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MANUFACTURE OF ALUM, FERRIC SULFATE AND SODIUM ALUMINATE

BY F. A. ABBIATI*

[*Read September 16, 1938.*]

The manufacture of aluminum sulfate, ferric sulfate and sodium aluminate is obviously of interest to those who in their normal routine use large quantities of coagulants. The position that aluminum sulfate occupies in the list of water-treating chemicals very clearly eclipses all other products combined and is of more widespread interest. Sodium Aluminate and ferric sulfate, as commercially available chemicals, are comparatively new to this field. They are included because we believe that they will play an increasingly important part as the science of water treatment proceeds towards a more complete understanding of the role of coagulants and the chemistry of their use. In adding these two products we are also mindful of the fact that the gradually increasing standard of public acceptance for potable waters will in a measure dictate treatment that is not attainable by the use of alum.

Manufacture of Aluminum Sulfate. Aluminum sulfates were known by the early Egyptians, Greeks and Romans and used extensively as mordants for the production of bright colors. The early alum used was the true alum or potash alum from natural deposits of Kalinite, $K_2SO_4 \cdot Al_2(SO_4)_3 \cdot 24\ H_2O$. This was produced by accumulating the fine crystals that effloresced from the natural deposits and also by leaching the matrix. Early users were influenced in their choice of raw materials by the ready availability of natural deposits and by the ease of purification, since potash alum can be separated from contaminating iron salts.

Alunite, an insoluble basic potash alum, $K_2SO_4 \cdot Al_2(SO_4)_3 \cdot 4\ Al(OH)_3$, was an important source of alum beginning with the 13th century. The neutral alum was produced by calcining the alunite until it lost water of constitution, leaving behind the soluble alum, which was in turn purified by leaching and crystalizing. Various other naturally occurring alums are known and have been used for their alumina content.

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The method of producing alum from pyrites schist has long been known and for several hundred years prior to the middle of the last century was the principal method of production. The ore used contained clay, pyrites and organic matter. Piles of this ore were burned. The SO_2 evolved was oxidized to sulfuric acid which in turn combined with the alumina present in the clay to form aluminum sulfate. This was leached out and ammonia or potash added to form the more readily purified salts. Approximately 100 tons of schist were required to produce a ton of potash alum. The extensive use of soluble alumina in water purification needed a cheaper and more efficient method of manufacture.

In 1844 a sample of aluminum sulfate prepared from clay was first offered as a substitute for potash alum. This event marked the entrance of alum as we know it on the commercial stage, a stage that was set by mushrooming industrial development to use lower cost alum in greatly increasing quantities

The process employing the acid extraction of available aluminum hydrate remains, in principle, unchanged to this day. Since aluminum sulfate contains a higher percentage of soluble alumina, the new product quickly came into favor, displacing the less economical double sulfates. The use of kaolin was in turn displaced to a large extent by bauxite, except in countries not having adequate resources of this higher grade ore. Some of the English alums are still made with clay as a raw material and although clay has been used in this country at various times it is not a serious competitor at present bauxite prices.

Alum from Bauxite. Bauxite is not a distinct mineral but a mixture of mineral substances. Since it is derived from granite or other igneous rocks it will contain the elements common to the rocks but in varying proportions. Alumina, iron oxide, silica, titanium dioxide and water are always present in substantial quantities. Bauxite for alum manufacture should contain 55 to 60% Al_2O_3. Iron is the principal contaminating element and should be as low as possible since most of it dissolves in the sulfuric acid and remains in the product. Silica and titanium dioxide present no problem to the alum manufacturer.

The following is a typical analysis of bauxite from British Guiana which is largely used in the United States:

Al_2O_3	60.3 %
Fe_2O_3	1.82%
TiO_2	1.20%

FIG. 1

SiO_2	30.0 %
Water (combined)	30.6 %

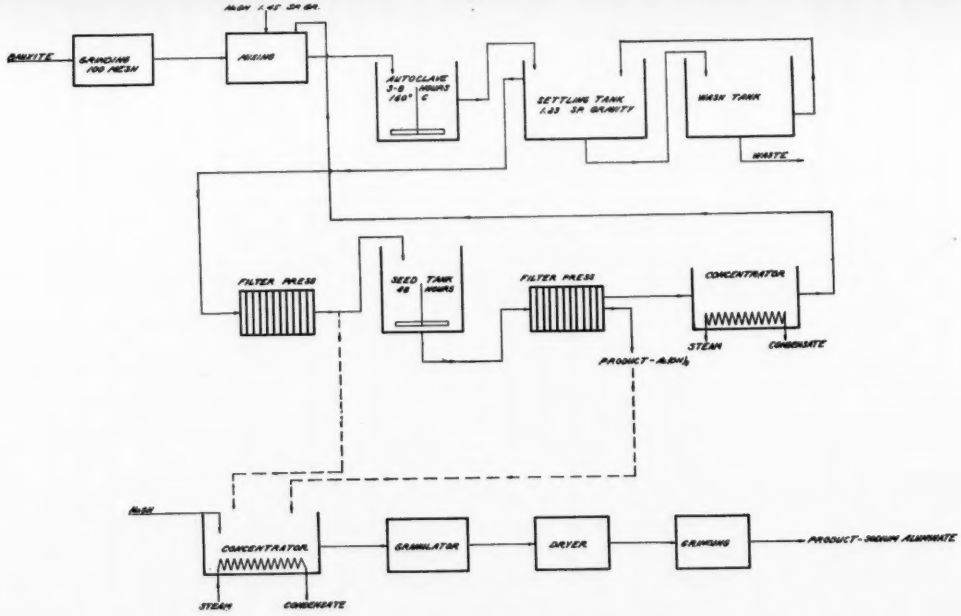
Balance—uncombined water and minor impurities.

High grade deposits of this ore are found in France, British and Dutch Guiana, Yugoslavia and in the United States. Production in this country is confined to Arkansas and Georgia at present. Our reserves of high grade ore are estimated to be in the order of 60 million tons. In view of our present consumption in the order of 500,000 tons annually it is possible that in the not too distant future it will be necessary to develop the use of lower grade ores or other sources of alumina. Processes used in the manufacture of alum are well standardized. They consist of digestion of finely ground bauxite in sulfuric acid, settling of insoluble, washing of insoluble and concentration of clear liquor. These operations may be accomplished by the use of batch equipment or the Dorr continuous counter current process, the one most extensively used in this country. A flow sheet of the process is shown in Figure 1.

High Insoluble Alum. Bauxite alum was manufactured years ago, containing all of the insoluble matter. The process used was similar to the one described, with the exception that a higher concentration of acid was used, and after digestion the mixture was run directly to cooling pans without settling or washing of residue. Recently the manufacture of this type of product was resumed and undoubtedly it will find use in applications where the high insoluble content has no deleterious effect.

Sodium Aluminate. The manufacture of sodium aluminate differs very little from the alum process just described, with the exception that an alkaline solution replaces sulfuric acid as the dissolving medium for aluminum hydroxide. Sodium aluminate was manufactured, as an integral step of the Bayer Process for the extraction of pure Al_2O_3, many years before a commercial demand existed for the product. Because of this fact, the flow sheet which we show covers steps of the Bayer Process as well as the final steps involved in making the two grades of sodium aluminate which cover the principal requirements of the American market.

The American rights to the Bayer Process were acquired by the Merrimac Division of Monsanto, and production of sodium aluminate and pure aluminum hydroxide was started in 1896 at its Woburn plant. The process was used to furnish pure aluminum hydrate for aluminum sulfate and chloride manufacture. The use of hydrate in the then infant aluminum metal industry soon outstripped all chemical



FLOW SHEET OF ALUMINIUM HYDRATE AND SODIUM ALUMINATE MANUFACTURING PROCESS

FIG. 2

uses, and the process is operated today principally to supply ore for metal manufacture.

In view of the fact that caustic soda will combine with silica to form soluble sodium silicate but does not affect the iron present, the Bayer Process requires bauxite ore of different characteristics than that demanded for the production of alum. The industry has set an upper limit of approximately 5% SiO_2 in bauxite for alkaline extraction. This can be readily understood by examining the following reactions:

$$NaOH + SiO_2 = Na_2SiO_3 + H_2O$$

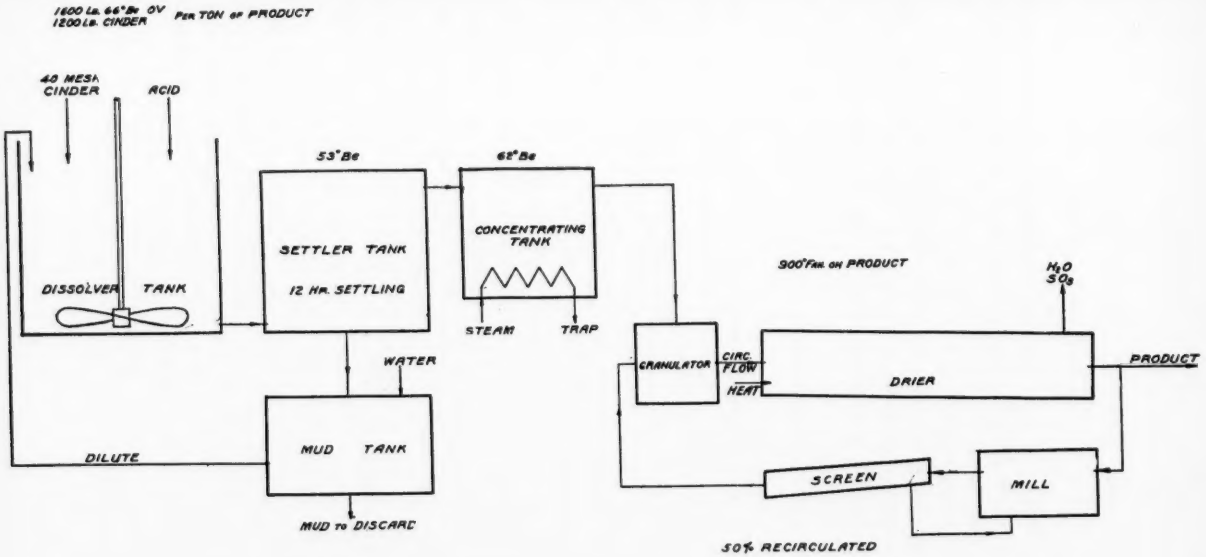
$$Na_2SiO_3 + Al_2O_3 + 9\ H_2O = Na_2O \cdot Al_2O_3 \cdot 9\ H_2O \quad \text{Insoluble.}$$

Each pound of dissolved silica robs the process of 1.7 lb. of alumina and 1.3 lb. of caustic soda. Alumina content should be in the range of 55 to 60% while the iron and titanium content of the ore for this process may exceed 10% without harmful effects on the process. A flow sheet of the process is shown in Figure 2.

Ferrisul. Ferrisul, anhydrous ferric sulfate, is the most recent addition to the field of chemical coagulants. Its advantage lies in the fact that it will form a stable floc over a wide pH range, a property that is not shared by ferrous coagulants. This property was recognized by water-treating chemists, and a limited use was made of these salts. Although commercial ferric salts were available in solution and crystal forms, the high freight costs and difficutly of handling materially limited their use. The usual practice was to oxidize the relatively inexpensive copperas with chlorine at the point of use

Our investigations in 1932 indicated that an anhydrous ferric sulfate would not be subject to the disadvantages inherent in either the solution or crystal form of ferric salts. We were further firmly convinced that this product might serve as a useful tool in the solution of problems that arose because of the narrow effective pH range of alum. It was decided to build a pilot plant in 1933 to furnish material more completely to evaluate the field. The increased demand that followed the introduction of this product necessitated the construction of a full scale plant in 1936. A flow sheet of the process is shown in Figure 3.

Pyrites cinder resulting from sulfuric acid production and sulfuric acid are the raw materials entering into Ferrisul manufacture. A suitable oxide for Ferrisul production has approximately the following composition:



—FLOW SHEET FOR FERAISUL MANUFACTURING—

FIG. 3

Fe_2O_3	92%
FeO	2%
Cu	Traces
Al_2O_3	1%
SiO_2	1%
S	1%

The processes which I have described reveal a general similarity to each other. This should be expected since in all instances we are forming the metal salt by dissolving the oxide in sulfuric acid and caustic and removing the principal insoluble impurities by sedimentation. It is interesting to note that in the reactions involving aluminum its amphoteric nature is illustrated clearly in that it first acts as a base in alum manufacture and as an acid in the manufacture of sodium aluminate.

LIME FOR WATER WORKS USE

BY J. G. THOMPSON*

[*Read September 16, 1938.*]

My understanding in regard to the desired subject matter to be covered in the following paper is that it be limited to the recitation of the standard specifications for, and a brief description of, the manufacture of lime products for use in water treatment.

The manufacturer's problem in supplying such products is a comparatively simple one insofar as it concerns the number of products involved and the required A. S. T. M. specifications he is called upon to meet in regard to them. The products are quick lime and hydrated lime.

Essentially the A. S. T. M. standard specifications for Quicklime for use in Water Treatment, Designation C-53-27 require, that—

(a) The lime shall be substantially free of core ash and dirt and shall be capable of disintegrating in water into a suspension of finely divided material.

(b) The standard quicklime for use in water treatment shall contain 90% of available lime calculated on the basis of the weight of the sample taken at the point of manufacture.

For Hydrated Lime for use in Water Treatment the A. S. T. M. standard specifications, Designation C-54-27, essentially require, that—

Standard hydrated lime for use in water treatment shall contain 68.1% of available lime calculated on the basis of the weight of a sample taken at the place of manufacture.

As a prelude to both of these specifications the identically same wording is used, as follows—

(a) "In the treatment of water for public supplies lime is used alone or with iron sulphate or aluminum sulphate to produce a precipitate which assists in the clarification of the water and in the removal of the bacteria by filtration. An excess of lime is sometimes used to remove part of the hardness of the water.

(b) "Lime and soda ash are used together for softening water.

(c) "The lime serves as a chemical reagent in water treatment. The only useful constituent of the lime is the calcium oxide capable of reacting with the other chemicals which are in the water or which

*The Lawrence Portland Cement Co., Thomaston, Me.

are added to it. Inert material, besides reducing the value in proportion to its amount, also makes more sludge to be disposed of for a given amount of chemical action and thus reduces the capacity of the equipment in which it is used."

An identical explanatory note also in regard to each of these products is worded as follows:—

"A standard composition without rejection limits is specified for the reason that lime of either higher or lower total oxides, available lime, calcium oxide or calcium hydroxide, than the standard may safely be used under suitable conditions for the purpose herein specified depending primarily upon purely economic considerations. In the present state of the art it is believed that the more serviceable type of specification for the products herein specified is that which defines a reasonable standard rather than one that fixes actual rejection limits. It is generally recognized that, other things being equal, lime meeting this standard is preferable to lime not meeting it and lime surpassing the standard should be considered at a premium."

Thus the manufacturer's problem is in turn resolved simply to the essentials of having a lime deposit from which to recover an adequate yield of comparatively high calcium content limestone or other source of material having a high calcium carbonate content, the necessary plant layout consisting of kilns, manufacturing, packing and loading equipment, and of course a properly experienced personnel in all departments.

This paper proposes to deal only with a set up having a limestone quarry as a source of raw material. In regard to such limestone deposits in a quarry, the specifications predicate the necessity of having a material with not less than about 95% calcium carbonate content, and limestone of this quality or better should preferably predominate in the total quantity of quarried rock recovered.

Digressing at this point, and referring back to the specifications calling for 90% available lime in the quicklime and 68.1% available lime in the hydrated lime, it might be well to state that raw material that will enable the manufacturer to produce a quicklime having 90% available lime content should also enable him to produce a hydrated lime having 68.1% available lime content.

In regard to the recovery of the raw material from the quarry, the recovery methods employed will of necessity depend upon the physical aspects of the deposit, its purity and uniformity in quality. Given a limestone deposit in undisturbed stratifications and of uniformly adequate purity, power shovels could be employed to recover

LIME PLANT
OF THE
LAWRENCE PORTLAND CEMENT CO.,
THOMASTON, MAINE.
FLOW SHEET
Drawn by J.E.T. Oct. 3/10
Not to scale.
LIMESTONE QUARRY
LIMESTONE
SPALLS TO CEMENT PLANT
No 1 KILN
No 2 KILN
HEARTH
CRUSHER
HYDRATOR
100 TON BIN
GAYCO SEPARATORS
PAN CONVEYOR
HAMMER MILL
TYLER SCREEN
TAILINGS RETURNED FOR RE-GRINDING
BATES
2-TUBE VALVE-BAG PACKER
THROW-OUT MILL
FINES FROM THROW-OUT
CHEMICAL HYDRATE BIN
DIVIDED BIN
TAILINGS FROM THROW-OUT MILL GO TO CEMENT QUARRY
WATER TREATMENT
LIMES
BATES
2-TUBE VALVE-BAG PACKER
4-TUBE VALVE-BAG PACKER
CHEMICAL
MASONS
HYDRATED LIMES
LAND
LIME
CRUSHED
QUICK LIME
FINISHING MASONS
PULVERIZED QUICK LIMES
PAPER MILL
FINISHING MASONS
LUMP LIMES

the rock, but let us consider the more usual quarry set up wherein there is a considerable difference in the quality of the rock shot down due to the difference in various strata present, slips, faults and so on, and in turn necessitating recovery of the rock by means of manual labor and hand picking in the selection of the correct material for kiln feed.

Essentially the problem is the same in what manner so ever the rock is recovered, that is, to provide raw material of proper size and quality to feed the kilns.

The kilns may be either rotary or vertical shaft kilns. The shaft kiln being the more frequently employed type, and the rotary kiln being more in the nature of a specialty producer, we shall confine our remarks to the operation of the shaft kiln.

Concerning the feed for such a kiln two factors must be taken into consideration, namely quality and size of the kiln feed rock. Selection as to quality depends largely upon the experience of the quarrymen and their ability to make proper selection by careful observation of any distinguishing identifications the good rock may have. Good judgment on the part of a quarryman in this connection is not so common as might be expected even in those of considerable experience. Rock having very close similarity in appearance all too frequently shows wide variation in chemical qualities and also in burning qualities when passed through the kiln. In regard to the sizing of rock for vertical kiln feed, the pieces should be fairly uniform, preferably about the size of a man's head, clean and entirely free of all spalls and small pieces. This sizing is desirabe because the rock will feed down through a kiln so loaded more uniformly and also the kiln so loaded will draught more thoroughly and uniformly.

Typical of a shaft kiln installation is one fired from Dutch ovens placed about half way up of its height with restriction in the diameter of its bore just above the ingress of the hot gases from the fires.

With a vertical kiln in operation the shaft of the kiln is kept full, or nearly so, at all times. The rock passes through the kiln by gravity, passing in turn through the rock storage zone, the firing zone and the cooling zone, and being changed in the progress from the raw rock to the more or less completely calcined and cooled state of finished quicklime as it is drawn off at the hearth at the bottom of the kiln.

The so-called draws at the hearth are made in batches depending upon the thoroughness to which the raw rock has been calcined or, as usually termed, burned, as observed back of the fires where the

material may be seen as it passes down the kiln shaft. The draws are, as a rule, regularly timed but this timing is changed depending upon efficiency of firing, unobstructed draughting, whether the rock is so-called hard or easy burning and the regularity of the movement of the whole kiln load down through the shaft.

When the quicklime has been drawn off onto the sorting platform or hearth at the foot of the kiln, the so-called pickers sort over each piece, examining it by heft and appearance, hammering apart any piece that they judge may have an unburned core, discarding such core found and separating all lime in each draw into various classifications such as Masons, Finishing, Water Treatment and Paper Mill Lump limes, Hydrator stock and so on. All core or otherwise unburned pieces, clinkers or pieces due to poor selection of any piece primarily in the quarry, and so on, are discarded.

A shipment calling for water treatment lump quick lime would be loaded directly into cars from the picking hearth at this point in the operations. Only well experienced operators may be used as pickers at the kiln hearth, because so much depends on their judgment and ability carefully and properly to separate the lime being worked over into several classifications. Theirs also is the responsibility for correctly reporting the kiln output, and providing the information that may function as a check upon the quality of the raw rock fed in and the efficiency of the burning as the rock passes down through the kiln.

The hydrator stock which has been collected from the picking operations at the kiln hearth is passed through a crusher and fed into the hydrator. There are several makes and different types of hydrators but these remarks will be in regard to a continuous type McGann hydrator that has been changed somewhat from the original installation to meet particular conditions. This hydrator consists of a horizontal tube now 34.5 ft. long and 5 ft. in inside diameter with a vent stack 2 ft. in diameter leading up from close to the feed end. Running longitudinally through the center of the hydrator is a shaft with paddles attached throughout its length. The hydrating water is introduced through a ring spray placed several feet up in the vent stack. This method of water introduction provides a means of trapping dust that would otherwise be vented and also of partially heating the water entering the hydrator proper. The water comes in contact with the lime just inside the feed end of the hydrator. A supplementary jet of water injected through the hydrator shell 5 ft. from the feed end is provided as a regulator for nicety of control for correct water content. The speed of the conveyor shaft with its paddles is regulated

by the operator as required to suit the hydrating progress, there being considerable difference in the speeds at which various limes may slake. Considerable heat is of course generated in the slaking process, but supplementary heat is provided by a long outside steam coil radiator for use in cold weather, and to keep the hydrator shell warm over any shut-down periods.

The Hydrated lime having passed from the discharge end of the hydrator is conveyed to a large storage and curing bin where it is held for forty-eight hours in order to give opportunity for any slow-slaking particles to hydrate more thoroughly. This stored hydrate in the curing bin is then fed to a series of air separators from which are delivered, classified in turn, chemical hydrated lime, masons hydrated lime, agricultural hydrated lime and land lime. A throwout mill, run in conjunction with the separator operations, extracts and throws out all unslaked particles and bits of core that may have come through the system to this point. These different classifications are conveyed to storage bins over the various packing machines and from there packed in bags for loading, or possibly loaded in bulk directly into cars for shipment.

Hydrated lime for water treatment would be selected from either the chemical or masons hydrated limes, this selection depending upon the users' instructions and behest, there being but little difference in these two—the chemical hydrate being only slightly finer in particle size, and having slightly higher available calcium oxide content.

COPPER SULPHATE FOR WATER WORKS USE

BY E. FITZPATRICK*

[*Read September 16, 1938.*]

When discussing the manufacture of copper sulphate, one naturally thinks of the processes followed in the early days and the developments that led to the processes used at present. We recommend to anyone who is sufficiently interested in the subject to read what J. W. Mellor presents under the heading "Copper Sulphate," in Volume III of his "Comprehensive Treatise on Inorganic Chemistry." The scope of this paper does not permit of making complete abstracts but we are giving some data based on the information obtained in this reference.

Copper sulphate has been known for 100 years or more as "Blue Vitriol" and also as "Cyprian Vitriol," the latter name, presumably, because it was produced on the Island of Cyprus, whether by natural or artificial means is not apparent. It is found quite abundantly in Chile as basic copper sulphate (brochantite) and as normal sulphate (chalconthite). These minerals are also found in various parts of Europe. They are probably the result of oxidation of chalcopyrite and subsequent leaching and crystallization.

The hydrometallurgy of copper is mostly based on oxidation and leaching with sulphuric acid or, where the copper is present as oxide, leaching alone, the product being copper sulphate in solution. The cost of producing copper sulphate crystals from these solutions, of sufficient purity for general marketing, is prohibitive due to presence of other salts such as the sulphate of iron. All methods of manufacturing copper sulphate, excepting some by-products outputs, are based on the solubility of copper oxide in dilute sulphuric acid and it is necessary to have it free from other soluble oxides. Metallic copper is soluble in concentrated sulphuric acid at a temperature of approximately 500° F. In dissolving copper oxide in dilute sulphuric acid, the following reaction takes place:

$$CuO+H_2SO_4 = CuSO_4+H_2O$$

With metallic copper and hot concentrated H_2SO_4 we have:

$$Cu+2H_2SO_4 = CuSO_4+SO_2+2\,H_2O.$$

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In the latter case, twice as much sulphuric acid is required as in the former. Besides the loss of half of the H_2SO_4, anhydrous copper sulphate forms and calls for special apparatus and extra handling.

Plant Operation

Solution. The process begins with the production of so-called "shot copper" which is made at the smelters. The shot copper is of irregular shape, somewhat similar to the shape of popcorn. The pieces are roughly ¼ to ¾ in. across. To a large extent, they consist of hollow shells. Shot copper is formed by pouring molten copper into a tank of water. Copper in this form provides a maximum of surface for oxidation and, at the same time, permits, during the next step of the operations, a free passage of air and solution between the pieces.

The shot copper is stacked in a tower known as an "oxidizer" which is a lead-lined tank, 10 ft. in diameter and 8 ft. high with a perforated bottom. This tank is super-imposed over another rectangular tank 18 ft. by 11 ft. in plan and 3 ft. deep. Around the inside upper part of the oxidizer is suspended a 6-in. lead pipe, coiled to a 6-ft. diameter ring with six ¼-in. openings spaced 1½ in. apart, so that the treatment acid may spray thoroughly over the copper.

The procedure is carried out in the following manner. A charge of dilute sulphuric acid (20% H_2SO_4) is placed in the lower rectangular tank which for that reason is called the "charge" tank. From the bottom of this tank a 6-in. pipe is dropped 34 ft. to the floor below where it is connected with a Pohle air lift. The spraying operation is intermittent and is arranged to function automatically. The dilute acid is kept at a temperature of about 180° F. by steam coils in the charge tank.

There is a row of oxidizers and charge tanks, in each of which is a batch of dilute acid. The operation starts off with spraying the solution in No. 1 tank after which the compressed air is shut off from the lift and diverted to No. 2 tank. Two minutes are allowed to elapse for the draining of the solution back to the charge tank from the copper and for the atmospheric oxygen to produce a thin film of copper oxide throughout the tower. At the expiration of the two-minute interval, the compressed air is automatically returned to the air lift, causing the solution to rise and spray over the copper in the oxidizer, dissolving, instantaneously, the film of copper oxide which has formed. The operations of oxidation and spraying continue until the free acid in the solution has been neutralized, which is accomplished in eight to ten hours.

Evaporation and Crystallization. The neutral solution of copper sulphate has a density of about 1.30 sp.gr. at 180° F. and a copper content of 10%. It is carried by lead pipes and non-corrodible 4-in. by 3-in. centrifugal pumps to an evaporator containing helical lead coils, where it is evaporated to sp.gr. 1.49 at 220° F. and copper content of about 15%. At that temperature it is forced through a filter press with muslin cloth filters and allowed to flow to the crystallizing tanks.

These tanks are 18 ft. long, 9 ft. wide and 6 ft. deep. The crystallizers are made deep purposely to allow for slow cooling and the formation of crystals of sizes called for in the trade. The crystallizers are covered with lattice frame covers divided into four sections which serve as supports for copper rods suspended in the solution. The rods act as collectors for beautiful large crystals. The crystallizing period is about eight days. When the crystallizers are unloaded after drawing off the mother liquor, the frames carrying the rods are hoisted by crane to a bin into which the crystals are dropped by rapping the rods. The crystals which form on the sides and the bottom of the crystallizers, are removed by cutting, and are hoisted in buckets and transported to another bin.

Washing Drying, and Sizing. The crystals collected on the rods break up sufficiently in falling into the bin, but the crystals from the sides and bottoms are formed into tight clusters and it is necessary to put them through a "breaker" which disintegrates the lumps.

All of the crystals pass to a centrifuge and are washed once with a small amount of cold water and then are transported by bucket elevator to a tower fitted with screens. Through the tower and screens, a current of warm air is passed continuously to remove the superficial moisture from the crystals. The screens are so arranged that the crystals above ½-in. in size pass through one outlet; crystals of ½-in. to ¼-in. through another and those smaller than ¼-in. through a third. They are marketed as large crystals, small crystals and granulated copper sulphate. A portion of the crystals is ground in a Raymond Pulverizer to pass 100 mesh. This is marketed as powdered copper sulphate. Another portion is ground in a special mill with a heating attachment to expel part of the water of crystallization leaving one molecule of water. This product is marketed as "Monohydrate" ($CuSO_4 . H_2O$). "Snow" copper sulphate is produced from a concentrated solution by rapid crystallization. The snow is of 80-mesh fineness.

A purity of 99% $CuSO_4.5H_2O$, is guaranteed on all grades of

crystals. These products usually run 99.25%. The balance is nickel sulphate, 0.60%, and iron sulphate, 0.15%.

The standard sizes of packages are 100 lb. in bags and 450 lb. in barrels. Packages of other sizes are supplied by special arrangement.

A monograph on water treatment has been written for the Phelps Dodge Refining Corporation by Dr. Frank E. Hale, Director of Laboratories of the Department of Water Supply of New York City, in which he covers the subject of Control of Miscroscopic Organisms quite completely.

Other uses for copper sulphate are:

Mordant for textiles	Pigments	Germicides
Wood preservative	Electric batteries	Process engraving
Leather industry	Hair dyes	Rayon manufacture
Fungicides	Copper salts of various kinds	
Insecticides	Reagent in chemical analyses	
	Medicine (emetic, tonic, astringent)	

CHARACTERISTICS OF COPPER SULPHATE (CRYSTALS)

Tri-Clinic System

Weight per Cubic Foot—Approximately 100 lb.

Solubility (Mellor)—Expressed in 100 grams of solution and 100 grams of water.

TEMPERATURE	0	10	20	30	40	60	100	140	180
Solution	12.5	14.8	17.2	20.0	22.5	28.5	43.0	44.5	43.0
Water	14.3	17.4	20.7	25.0	28.5	40.0	75.4	80.2	75.4
	$CuSO_4 . 5H_2O$						$3H_2O$	H_2O	

ACTIVATED CARBON—MANUFACTURE AND SPECIFICATIONS

BY E. A. SIGWORTH*

[*Read September 16, 1938.*]

Since the first application of powdered activated carbon about eight years ago, the acceptance of this material for removing tastes and odors has been so rapid that there are now over 1,000 plants throughout the United States using this material. The very satisfactory results obtained have been publicized to such an extent that quite a number of plants in foreign countries have followed the practice in this country and instituted the use of powdered activated carbon.

Manufacture. The raw material employed for the manufacture of activated carbon may vary widely depending upon its availability and the type of carbon to be made. For example, in the manufacture of activated carbon employed in gas masks, the raw material is usually cocoanut shells. Other materials that have been employed to make decolorizing and deodorizing chars are charcoal, lignite, wood and peat.

It is essential that the material used in the manufacture of activated carbon be previously charred under very carefully controlled conditions to insure the ready activation of the carbon in the subsequent operations. The char obtained from the preliminary operation contains impurities that have been variously described as hydrocarbon complexes. These tend to prevent adsorption and consequently must be removed. Activation of the carbon accomplishes this removal and consists, in general, in heating the char to relatively high temperatures under very closely controlled oxidizing conditions. The temperatures employed in activation will vary with the different manufacturers, although the average temperatures employed are about 800 to 900° C. Oxidation is controlled usually by using mild oxidizing gases such as mixtures of steam, air, and flue gas.

The results accomplished in this activation or cleaning of the carbon surface can be realized when it is considered that the ability of the activated material to remove impurities from solution is from 100 to 1000 times greater than that of ordinary charcoal. During the entire manufacturing operation, extremely close control is necessary in order to accomplish a uniform activation to the desired degree.

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This, in turn, depends upon the particular application for which the material is intended. The final step in the process is grinding the material and packaging for shipment. Grinding is again closely controlled for uniformity and the sizing is dependent upon the uses that the carbon is to serve.

Carbon Specifications for Use in Water Supplies. The Water Purification Division of the American Water Works Association established in 1933 a Sub-Committee on Specifications and Tests for Activated Carbon. This Sub-Committee after intensive work and study prepared a final report that was published in the July 1938 issue of the JOURNAL of the American Water Works Association. This report is a thorough study of the problem and is recommended to those interested in more complete details on the subject.

The general requirements as suggested in the Committee report are quoted in part as follows:

"1. *Impurities*: The activated carbon shall contain no soluble mineral or organic substances capable of producing deleterious and injurious consequences upon public health.

"2. *Moisture*: The moisture content of activated carbon when received shall not exceed eight (8) per cent by weight.

"3. *Density*: The carbon shall be in the powdered form and of such characteristics that it will readily wet down and go into suspension. It must not settle rapidly; yet must not have a tendency to float on the surface of the water to which it is applied, after the material has been thoroughly wetted.

"4. *Fineness*: The powdered material shall be of such fineness that no less than ninety-nine (99) per cent will pass a 100-mesh sieve and no less than ninety-five (95) per cent will pass a 200-mesh sieve as tested by the wet-screen method.

"5. *Adsorption Capacity*:

a. The adsorption capacity of an activated carbon shall be evaluated indirectly on the basis of its ability to remove phenol from water by adsorption under standard conditions of test."

Under Specific Requirements the report states:

"Note: The use of the phenol specification alone (Option A) and its supplementation by the measurements of the threshold odor reduction (Option B) shall be governed by local option.

"1. *Phenol Value Requirement*: (When Option A guarantee is selected).

"Note: Since activated carbons are available and now found in use with phenol values ranging from thirty (30) to almost ten (10),

with proportionate prices, the definite specification for this value is left open to local experiences and requirements.

"a. The phenol value of the activated carbon to be furnished shall be.....( ) (whole basis) or less. The material shall retain this value after being properly stored in the plant warehouse for a period of 120 days.

"b. The phenol value specified shall be subject to a permissible tolerance of plus or minus ten (± 10) per cent before the premium penalty adjustment shall be applied.

"2. *Threshold Odor Value Requirements*: (When Option B guarantee is selected).

"a. The competitive bid samples qualifying in general requirements shall be further evaluated in terms of their respective abilities to remove directly odors from the particular water supply for which the purchase of the materials is intended.

"b. The carbon performance test shall comprise a series of comparative laboratory tests which shall approach and duplicate the plant conditions, as nearly as it is practicable to do so, with respect to the addition of the coagulant and any other pretreatment, mixing time, degree of agitation during mixing, and settling time, as well as the point of application of carbon and the required dosage to reduce the odor to the particular tolerable threshold value suitable for local consumer delivery.

"c. The original odor of the untreated water, together with the residual odor of the treated water, will be determined by means of the Threshold Odor Test outlined herein.

"d. Preference will be given to that carbon which indicates the greatest amount of odor removal per unit cost per unit water treated.

"e. The subsequent shipment samples of the successful bidder shall be compared and checked by means of the Threshold Odor Test against his original bid sample, which shall serve at all times as a reference sample."

Threshold Odor Test. Impurities that cause odors in water are present in such small proportions, and are of so complex a nature, that they have defied separation and quantitative measurement. Therefore the actual evaluation of activated carbon for removal of minute quantities of impurities actually present in water supplies was quite difficult.

The primary purpose for which activated carbon is purchased is to remove tastes and odors from water. In reality, the objectionable characteristics removed are odors even though the consumer may

complain that the water tastes badly. It has been stated by Buswell[1] that psychologists apparently recognize only four taste sensations—sweet, bitter, sour, and salty. Thus it can be realized that tastes characterized as moldy, musty, pigpen, ripe cucumber, etc., are actually odors rather than tastes, and it was on this basic principle that the threshold odor test was developed by Charles Spaulding.

The purpose of this test is to determine the intensity of odor in water and is accomplished by diluting the sample to be tested with odor-free water to a point where the odor is just detectable. The technique is very simple and with a little instruction can be followed by practically anyone. The procedure is as follows:

In one Erlenmeyer flask are placed 250 ml. of odor-free water. In another similar flask is placed the sample diluted with odor-free water to a total volume of 250 ml. Both flasks are heated until the temperature of the water reaches 65° C. Each flask is then shaken vigorously and the warm vapors inhaled to determine whether the odor is detectable. If the odor is detected, the test is repeated using less of the sample and more odor-free water. If the odor is not detected, then more of the sample and less odor-free water are tried. By means of systematic dilutions, the point is finally reached where the odor is just detectable, and at the next lower dilution it is not detectable. The threshold odor point is considered that dilution at which the odor is just noted, and the threshold number is obtained by dividing the number of milliliters of the sample used into the total volume of water which in this case is 250 ml. For example, if the odor is last noted when 10 ml. of the sample are diluted with 240 ml. of odor-free water, the threshold number would be 250 divided by 10 or 25. Therefore, the threshold number is directly proportional to the odor intensity, low values indicating low intensity, and high values high intensity.

Where only one person is carrying on threshold tests, there is a psychological factor involved in that he knows which flask should contain the odor. He may, therefore, be unconsciously prejudiced in his selection. When activated carbons are being evaluated, this factor should be eliminated by having two operators, one to make the dilutions, and the other to do the smelling. The one doing the smelling thus does not know which flask contains the odor.

The degree of accuracy obtainable in threshold-odor tests is really quite surprising. An operator can check himself quite accurately once

[1]Buswell, A. M. The Chemistry of Water and Sewage Treatment Chemical Catalog Company, New York, 1928.

he has developed his sense of smell to this particular test and to the odor present in the water. Different individuals will not necessarily check each other due to the fact that the sense of smell is more keenly developed in some people than in others. It is therefore advisable during evaluation tests to have one man only to make the observations throughout the entire series.

Utilizing the senses for testing purposes is not new or novel, and is not limited to the water field. Everyone has heard of tea-tasters, whisky-tasters, wine-tasters, and butter-scorers. Such experts can easily demonstrate their accuracy by going back over previously tested, freshly coded samples, and give them exactly the same numerical rating as when first tested. Fortunately, the threshold odor test is now so well developed that one need not have years of experience to become proficient in carrying out the tests accurately.

Loss of Efficiency During Storage. Unfortunately in some cases it has been found that the efficiency of activated carbon is reduced during storage. Since a good carbon will retain its activity when properly stored, specifications should call for a guarantee by the manufacturer to this effect.

Ash Content. Some municipalities have set specifications limiting the ash content of activated carbon. Such a limitation is not necessary, and might in fact be detrimental to the best interests of the water works field, by eliminating from consideration a material that might be superior for odor removal. Requirements in this connection should therefore be that the carbon should contain no water-soluble impurities to such an extent that they will be harmful or injurious to human health.

Conclusion. Specifications for activated carbon should, above all else, contain a clause requiring the material to be effective in eliminating odors from the individual water as determined by the threshold odor test.

Phenol values should not be considered as indicative of the efficiency of carbons in removing odors from water. In order to include active, and exclude inactive carbons it is suggested that the upper limit for the phenol value be set at 30 p.p.m.

To insure proper operation of the carbon in the plant it is desirable to include specifications on moisture content, fineness, dispersion, suspendability, and protection against loss of efficiency during proper storage.

For greater details on specifications reference is made to the re-

port of the Sub-Committee on Activated Carbon, Water Purification Division of the American Water Works Association.

For information on proper storing of activated carbon attention is called to the March and April 1937 issues of the *Journal of the American Water Works Association.*

LAYING LINED AND WRAPPED STEEL PIPE AT NEEDHAM, MASS.

BY ROGER G. OAKMAN*

[*Read December 15, 1938.*]

In the improvement of our distribution system on the main line from the new pumping station at Charles River, an appropriation was granted for laying a new pipe line in Charles River Street from Pine Street to Grove Street, connecting at each end to the existing 14-in. water main.

After carefully analyzing the cost of steel pipe as compared with cast-iron pipe and studying the features of each, it was decided to purchase steel pipe from the Youngstown Sheet and Tube Company. The pipe was delivered to us in two gondola-type freight cars at the nearest railroad station, about ¾ mile from the job. C. P. Burrill of Brockton, Mass., unloaded the pipe and transported it to the side of the ditch, placing the lengths so as to require a minimum amount of shifting. A 6-wheeled truck, equipped with a crane was employed. Extending from this truck, was a two-wheeled trailer, attached by a long pipe-shaft, adjustable to meet the requirements of any length of load. A second truck, equipped with a crane was also used. This provided a means for picking up the pipe from the cars with a sling near the end of each pipe. Old fire hose was fastened to the rocking bolsters and supports of both truck and trailer. The slings were also run through fire hose, which served to protect the exterior wrapping of the steel pipe from being scuffed or injured. These trucks carried about 15 lengths of 40-ft. pipe in each load. The pipes were unloaded along the line of ditch very efficiently and quickly by means of the two trucks, one running ahead and the other backing with the load. It cost between 4 and 5 cents per foot to transport this pipe from the cars to the job.

The route over which we proposed to lay the pipe line conformed to the new route of Charles River Street as laid out by the County Engineers. As the travelled way had not yet been changed, we were obliged to cross and crisscross the old road, an 8-in. gas main and the existing 8-in. water main many times. We also had to dig the ditch down the center of the road for a distance of about 300 ft., as well

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as to go through a wooded section with a brook crossing. In the total distance of 3400 ft., there was a straight run of only 800 ft., the rest of the line being on long flat curves of from 550 to 1000 ft. radius.

The steel pipe purchased was 14-in. in outside diameter, weighing 30.92 lb. per ft. and slightly less than ¼ in. in thickness. It was lap welded, designed to carry a working pressure up to 375 lb. per sq. in. and came in 40-ft. random lengths. The pipe was lined with bitumastic B-70 lining, a coal-tar-base enamel as manufactured by the Wales-Dove Hermiston Corporation. This lining will serve as a protection against any internal tuberculation, corrosion or incrustation and will insure high initial and sustained flow capacities that will assist in low pumping and operating costs.

The exterior of the pipe is protected with a combination of asphalt-base enamel with saturated, rag-felt PRX-1 wrapping. The pipe, after cleaning, receives an asphalt priming coat, two separate hot coats of Texaco Asphalt, a saturated rag-felt coat and another coat of Texaco Asphalt. The whole is then protected with a coating of heavy Kraft paper. This lining and coating of the pipe was done by Hill, Hubbell & Co., division of the General Paint Corporation.

The pipes were connected by Dresser Compressor-Type couplings. This coupling has an inner ring which serves as a collar for the two pipes to slip into. Two rubber gaskets are drawn against this collar by means of 8 bolts passing through two outer rims that, when pulled up, squeeze the rubber gaskets against the collar and pipe, insuring a bottle-tight joint with a maximum amount of flexibility and allowing the pipe to fit the ground contour and make easy bends.

At each end of the job and for our hydrant connections, we used an adaptor with a Dresser coupling to connect the steel to the cast-iron mains. Three 14-in. gates were installed in the line with a Dresser-type coupling incorporated as part of the gate.

We lowered the pipe into the trench with a four-legged derrick and attached winch. As some of the curves were too sharp to be made by the pipe with the maximum deflection allowed by the couplings (4 degrees), it was necessary to install a few special angular couplings. The pipe was cut in two by means of a Strickler cutter that allowed some of the curves to be made by means of short tangents.

About 2/3 to ¾ of the pipe line was laid from on top of the ground both in straight work and around curves. The pipes were rolled across the ditch on supports placed about 40 ft. apart. While in this loose position, the "dope" man repaired with hot enamel all spots that showed indications of being bruised or scuffed. The rings and

gaskets were slipped over the ends of the first pipe, with the middle ring or collar following. The next adjacent pipe was then inserted and the bolts drawn up, closing the coupling and compressing the rubber rings against pipe and collar. The men then moved up the trench to the next joint. The "dope" man, in the mean time, primed the coupling and the exposed ends of pipe. Hot asphalt-enamel was then poured over and around the coupling to insure a seal of approximately the same thickness as the coating. This completing material is heated to a high temperature and poured over the coupling with an open-end sprinkling-can. The drainings are caught in a semi-circular drip collector and dumped back into the heater to be used over again.

After 4 or 5 pipes had been coupled together, horses were set up just back of each joint. These horses were about 6 ft. long and 5 ft. high, with legs and braces of 2-in. by 6-in. plank and a back or cross piece of 4-in. by 6-in. stock. At the center of the back, the edges were whittled down to form a round section for the snubbing ropes to work around. The snubbing ropes were fastened to heavy hooks and slings protected with fire hose so that the pipe wrapping would not be injured. The pipe was then lowered by means of the snubbing ropes, care being taken not to lower any section a distance greater than that corresponding to the allowable deflection of the joints.

By laying and connecting the pipe above the trench, it was not necessary to dig a wide trench and coupling holes. We could also couple up and join the pipes at a considerable saving over that of working in the trench.

I might mention at this time one of the little sidelights that always come up on these jobs. We were making a connection to an 8-in. main across the street and had the pipe all cut out when we noticed a crack on the cast-iron bell. After cutting out this bad pipe, it was noted upon examination that apparently this was an old crack. We were fortunate that it hadn't reached the point of failure, as this line carried a pressure of 100 lb. per sq. in. As this line is on the force main from the pumping station, disastrous results might have occurred had it burst.

This job was started on July 5, 1938 and completed on about October 10. Employed on the job were 22 men and 1 truck. The appropriation for this project was $20,000 and the completed job cost approximately $15,000.

THE USE OF LINED AND WRAPPED STEEL PIPE IN THE AUGUSTA WATER DISTRICT

BY SIDNEY S. ANTHONY*

[*Read December 15, 1938*]

The Augusta Water District, a quasi-municipal corporation Chartered on March 26, 1903, includes all but Ward 5 of the eight wards in the city of Augusta and is authorized to serve, in addition, the towns of Manchester and Winthrop and the Veterans Administration Hospital in Chelsea. It is authorized to take water from Carleton Pond in Readfield and from Cobbosseeconttee Lake in Winthrop, Manchester and Monmouth.

All water supplied since 1912 has been taken from Carleton Pond by means of two electrically-driven, centrifugal pumps of 4 m.g.d. capacity each, or a little over 5 m.g.d. together. A third similar pump is connected to Cobbosseeconttee Lake, having been installed in 1932, replacing a Deane double-acting, steam pump installed in 1906 and seldom used.

Service capacity is maintained within the city limits, 9 miles from the ponds, in two concrete-lined reservoirs, one of 6 m.g. and the other of 10 m.g. capacity, and in two 300,000-gal. steel standpipes, one at the Veterans Hospital Reservation and the other in the Cushnoc Heights section described by the author before this Association in 1935.

A 24-in. supply main enters the city toward the service reservoirs at some distance north of the main highway from Augusta to Lewiston. In 1925, a 16-in. branch was taken from this supply main and run cross-country to the main highway and thence to the southerly section of the city. This was done on the recommendation of our consulting engineers, to provide more adequate fire flows in the State House and Executive Mansion sections, as well as to make it possible to supply the adjoining city of Hallowell, in case of need. From the point where this 16-in. line enters the main road, the ground rises slightly to the west nearly to reservoir elevation; then it falls to a brook valley before rising again for nearly a mile to elevation 400.

The residents along the main road all wanted water service, but it was feasible at the time to serve only those who were located on

*Superintendent and Engineer.

the first rise. The pressure at the kitchen faucet of the last taker was only 8 lb. per sq. in. In 1927, the residents of the Lewiston Road, beyond the existing main, petitioned the Public Utilities Commission for an order requiring the District to serve them. In order to serve the petitioners, it would have been necessary to install a booster station and standpipe at the town line, and distribution pipes between, with services and hydrants to a total cost of about $70,000. The revenue to be derived was shown to be about $50 less than the pumping bill at the booster station, to say nothing of fixed charges. This petition was denied.

In 1937, the same petitioners reopened the case under new leadership and, since there had been no substantial increase in the demand, and costs were about the same, their petition was again denied. However, during the winter of 1937-1938 the author studied the project at length, conferred with the residents of the section and developed a compromise system that would serve part of the territory in question without a booster station and with feeble fire protection and domestic service.

The Trustees of the District were and still are convinced that this section is the most likely in the city to develop new business. Without water it would not develop, and without development it could not have water. There the matter stood until this spring when the Trustees voted to make the extension.

The system devised is composed of 4,000 ft. of 8-in. pipe, with appropriate valves, four hydrants and a tee left for a future hydrant installation, a small standpipe of 15,000-gal. capacity and twelve services, half on one side and half on the other side of a 30-ft. three-lane, concrete highway built in 1936.

The high point at the end of the existing line of 6-in. pipe was so near the hydraulic gradient that the use of water beyond would rob the existing customers at that point, so that a storage of some sort was imperative. The site chosen for the storage was at the end of the proposed main, and a small temporary standpipe was selected, with the top just above reservoir elevation with the idea of installing a larger one farther out if and when the booster station should be installed and the necessary extension made some time in the future.

During the past few months lined and wrapped steel pipe has been discussed frequently by the Board and others of our acquaintance. Accordingly inquiries were directed to manufacturers as to the price of this material. The purchase price was found to be 30¢

per ft., lower than unlined cast iron, and we were satisfied that the life was about as long if properly installed. We purchased 4,000 ft. of 8⅝-in. outside-diameter, lined and wrapped pipe, lined with Barrett coal-tar bitumen and wrapped by Hill Hubbell & Co. of Cleveland in the plant of the Youngstown Sheet & Tube Co. in Youngstown, Ohio.

A 15,000-gal., welded, steel tank was purchased from the Pittsburgh Des Moines Steel Co. and hydrants and valves from the Rensselaer Valve Co. of Troy, N. Y.

Since there were no sharp bends in the line, it was decided to use random 40-ft. lengths that actually varied from 36 to 45 ft. The maximum curve was 4 degrees. The pipes were connected by means of Style 38 Dresser Couplings, which in turn were coated with an asphalt compound after assembly. Gate valves were used that were equipped with half a Dresser Coupling at each end. On hydrant branches, the same style of gate valve was used, with a steel-to-cast-iron adaptor to the hub of a standard, hub-end hydrant. All hydrant tees, a cross tee for future installation of branches in the Leighton Road which was crossed, and a 14-degree ell, where the standpipe branch left the main line, were fabricated of steel pipe and lined and wrapped with the same materials as the pipe.

We were urged to assemble the pipe above ground on timbers laid across the trench, but as this line was only 3 ft. from the edge of a heavily travelled, main highway, we decided that the interests of safety could best be served by having as little trench open at one time as possible. We felt that the above-ground method of assembly would be economical only if long sections could be assembled and lowered at one time. Another reason why we preferred to lay the pipe directly in the trench is that we always plan to lay mains on blocking and that we bed them in fine backfill by hand. This may be an unnecessary precaution in the case of steel pipe but, since adopting this method many years ago, we have never had a break in a main caused by settlement.

Service connections were made by means of tapping saddles of maleable iron with double, wrought-iron straps around the pipe, the corporation cock being threaded into the main as well as the saddle. This method added somewhat to the cost of each service, but we were not then, and are not yet, satisfied that the thin wall of a steel pipe will hold a corporation cock securely for many years, when there are not over three threads in the pipe wall. Service lines to the

opposite side of the highway were driven through without difficulty, either by means of air or of water jets. We find that the air jet works well in sand or hardpan and that the water jet works best in clay soil. All of these materials, as well as ledge, were encountered. Where ledge is present, we move laterally along the trench until a low spot is located and drive through that, even though it may be necessary to move some distance away from the lot or at other than a right angle.

Service pipes are located to the center of every third lot, with curbstops left on each of three branches so that services can be run to three houses from one crossing. Where pressures are low, under 25 lb. per sq. in., 2-in. lined and wrapped steel pipe is used for road crossing, otherwise, 1-in. copper pipe is installed. This method of highway crossing was devised, because we were determined that we should not be accused of being the first to excavate a brand new concrete highway that the local residents had been trying to get for many years.

Final costs of this project were as follows:

4,030 ft. of lined and wrapped, steel pipe at $1.05 per ft. plus labor, fittings and sundries	$10,451.61
Four hydrants with gate valves, boxes, and excavation	563.16
One 15,000-gal., welded steel standpipe	680.00
Foundation for standpipe	290.92
Twelve service connections, not yet completed (estimate)	300.00
Total cost of project	$12,285.69

Work was started on July 11, and the first section, about 360 ft. long, laid on July 13. From then on, the work was carried forward without interruption until September 15 when the standpipe was raised and the water turned on. Due to damage to the paint of the standpipe during erection, it was necessary to empty the system, repaint the standpipe and refill it during the week of September 19. It was empty when the hurricane of the 21st was approaching, but we had warning enough so that it was filled safely before the wind reached its maximum velocity of 65 m.p.h. at about 8 p. m. on that day. Later that week, it was necessary to empty the standpipe again and to touch up the paint that had been wet when the standpipe was filled.

This project was entirely financed out of current funds by the District. In fact, no project of the Augusta Water District since 1926 has been financed in any other way, except the submerged river-crossing installed in 1936-1937, about 85% of the cost of which is still being carried on temporary loans with a Boston bank at 1% interest.

FACTORS AFFECTING THE COST OF DISTRIBUTING SYSTEMS

BY WILLIAM W. BRUSH*

[*Read September 14, 1938.*]

It is advisable first to define what portions of a water system should be included as the distribution system. The mains and valves are clearly part of the system, although these are not properly to be taken as a cost to be wholly borne by the water consumers, as a substantial percentage is usually required for fire protection and the annual charges on such part should be paid by a general tax and not by the water rates. The hydrants with their branches and appurtenances represent what should be a general tax charge. The services and meters are wholly chargeable to the consumers.

As pumping is required in some systems and not in others, the author prefers to consider it as a separate function, although where required, it is necessary in providing for the delivery of the water at the desirable pressure. When pumping stations are used to raise the hydraulic gradient for the delivery of the water, they are part of the delivery system, unless they are located in or immediately adjacent to the distribution system. The pumping stations that deliver the water directly into the distribution mains or distribution reservoirs, are believed by the author to be part of the distribution system. However, to simplify the presentation of the subject, in this paper, it is assumed that pumping stations are not to be included.

The restoration of pavement over cuts made to install mains and their appurtenances is part of the original cost, if the pavement was in place when the main was laid.

No attempt will be made to subdivide the construction costs or operating and maintenance costs between the water consumer and fire protection and other uses properly to be paid for by a general tax. The factors affecting total costs will be given, leaving to others the task of endeavoring to say what part is the water consumer's burden and what part should fall on the general taxpayer.

Construction Costs

The mains, valves and hydrants constitute eighty or more per cent of the original or investment cost of the distribution system.

This cost is substantially affected by a number of causes some of which are subject to some control by water officials while others

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are beyond their control. The ones that are wholly or largely beyond control are:

(1) Character of materials to be excavated in laying mains;
(2) Character of pavement cut;
(3) Depth of frost penetration;
(4) Sub-surface congestion due to installation of various structures within street limits;
(5) Congestion of surface traffic which affects handling of excavated material, construction materials, activities of workmen and use of machines.

Those causes which are in part controlled by the officials in charge of the work are:

(1) Character and size of pipe used;
(2) Depth of cover;
(3) Character of joints;
(4) Spacing of valves and hydrants;
(5) Size and type of valve boxes or chambers used;
(6) Water pressures carried;
(7) Maintenance of carrying capacity by adequate coatings or by treatment of water to minimize tuberculation or by both.

With these twelve variables that may affect the cost of constructing a distribution system, it is obvious that the cost of distribution systems that were installed to supply two communities that were virtually identical in size might vary materially.

If we now bring into the picture the population and its density, the manufacturing and business establishments and their locations and water requirements, the possibility of further and wider variations in construction cost of an adequate distribution system becomes apparent whether the cost be reduced to an average for a mile of main, a tap, a consumer, a million gallons daily consumed or any other unit. Probably, the unit that would give the least variation in the figure worked out for a number of communities located in an area like New England would be the inch-mile of main. To work out the cost on such a unit would require a detailed schedule of the lengths of the respective sizes of mains. Furthermore, the variations in costs are so wide as to indicate that unit costs are of only slight value in developing an estimate of what a distribution system for a given community has cost or what such a system would cost for a given community that now has no water supply system.

A striking illustration of the variation in construction cost of water mains due to density of sub-surface construction and density of surface traffic, is given by figures furnished to the author by Loran D. Gayton, City Engineer, Chicago. Mr. Gayton reports the following costs per foot of main laid, the work being done by the city day labor forces and the figures representing 1930 conditions:

SIZE OF MAINS	COST PER FOOT OF MAIN	
INCHES	UNIMPROVED STREETS	IMPROVED STREETS
6	$1.45	$ 9.08
8	4.48	9.08
12	5.88	10.65

It will be seen that in the improved streets, the difference in cost of materials for the different sizes of pipe was almost lost in the cost of excavation, laying and repaving and the items incidental thereto.

Another set of figures, giving 1930 conditions and covering pipe laid in a New England city, is that furnished by Caleb M. Saville, Manager and Chief Engineer, the Metropolitan District Commission, Hartford, Conn. Mr. Saville reports for 1930, the following figures:

COST OF INSTALLING CAST-IRON WATER PIPE IN 1930

SIZE	COST PER LINEAR FOOT		PER INCH IN
INCHES	MATERIAL	TOTAL	DIAMETER
2	$0.57	$1.33	$0.67
4	0.71	1.32	0.33
6	0.85	1.70	0.28
8	1.23	2.30	0.28
10	1.95	2.75	0.28
12	2.14	4.13	0.34
16	4.78	8.64	0.54

These costs are without overhead costs. To provide for overhead, the labor item is to be increased by 15%, materials by 10% and an additional 10% to the sum of the two. The Hartford overhead is figured as approximately 23% on combined labor and material costs. The additional cost for cutting and restoring improved pavement is $3 per foot for 6-in. pipe.

To indicate how prices of pipe installed may vary in various parts of the country, a comparison of the average costs for pipe installed in 1930, in Louisville, Ky., with those given for the Hartford District, shows that for the 4- and 6-in. pipe the Louisville costs are 74% of Hartford and for 8- and 12-in. pipe 70 and 71% respectively. The cost for labor in Louisville is relatively lower than the material prices.

Costs of Maintenance and Operation

Let us now turn to the consideration of maintenance and operating costs. We all know that the practices in maintenance and operation vary greatly, apparently without any compelling reasons. One city keeps men on duty day and night for emergency service. Its nearby neighbor depends upon gathering a gang from the homes when and as required. One city spends substantial sums in protecting its water mains from unusual external loads and carefully supervises the work of the other city departments and public utility companies to see that the mains are safeguarded. Its neighbor does not consider such expenditures to be justified. Here again is found a reason for variations in cost of carrying on the water distribution work.

The more important items in the cost of maintaining and operating a distribution system are as follows:

1. Repair force together with their headquarters and equipment.
2. Night and holiday emergency crews.
3. Breaks in mains and hydrants.
4. Leaks.
5. Systematic operation of valves.
6. Systematic inspection and repair of hydrants.
7. Meter testing.
8. Meter reading and billing.
9. Obsolescence.
10. Loss in carrying capacity.

Comments will be made on each of these factors.

Repair Force Including Headquarters and Equipment. There are few Superintendents who are allowed all of the force and equipment that would be considered fully adequate for the maintenance and operation of the distribution system in accordance with a standard that would represent first class housekeeping for this part of the work. The headquarters provided are also seldom up-to-date buildings designed to meet present day needs.

While there would be a saving in some of the current, every-day expenditures if the plant were maintained by a fully adequate force, it is probably true that the higher standard of maintenance would cost more than that which is now usually feasible with the money appropriated for such purpose.

Likewise, the cost per year for adequate repair headquarters would be higher than the cost of the type of building frequently found assigned for this work.

In the author's opinion, the lower cost is not a sufficient reason for failing to provide the force, equipment and headquarters needed to perform this part of the work in a manner that would call forth commendations from those served and permit prompt adequate service to be rendered at all times.

Night and Holiday Emergency Crews. No fixed rule can be set up and properly used to determine when emergency crews should be provided. Such crews add to the expense as their personnel can seldom be fully employed on effective work. The larger cities find they are necessary to handle shut-offs where breaks occur and to minimize the damages for which the water department may be liable if a quick shut-off of escaping water is not accomplished after a broken main is reported.

The author has been connected with numerous law suits for damages caused by water escaping from broken water mains, and in New York State, liability for such damages hinges on whether the city had the men to respond quickly after a break was reported; was up-to-date equipment available and used to shut down the valves, such as valve keys driven by motor truck engines, and were the valves actually promptly shut down and the flow of escaping water stopped? In New York, emergency crews and trucks equipped with motor-driven valve-closing devices are standard practice, which adds to the cost in one direction but cuts down the cost in other ways.

Breaks. Our distribution systems are made up almost wholly of cast iron-pipe cross-connected at frequent intervals, usually at each street intersection. Due to the characteristics of cast iron, when a break occurs usually a relatively large flow of water takes place. However, such breaks are comparatively few, and cast iron has given excellent service in mains for over 100 years and has been subject to much abuse while performing this service.

If water mains are properly laid with an earth cover suitable for the thickness employed and are thereafter protected from movement and from external loads such as may be imposed by another sub-surface structure crossing over or under the water main in such a manner as to impose an additional load on the water main, there is practically no likelihood of a break occurring. In New York City, where such care has been exercised in an increasing degree for the past 25 or more years, the breaks in water pipes are decreasing in spite of the great increase in the miles of mains in use and the greater age of the older sections of the system.

Whether the cost of repairing breaks and the damages resulting

therefrom is greater or less than the cost of reducing the number of such breaks can never be definitely determined, but again good housekeeping is on the side of prevention rather than repair.

Leaks. To locate and stop underground leaks costs money; to let them continue with the probable ultimate rupture of a main may cost still more money. With the present day devices to locate leaks readily obtainable by any community, the cost of such work should be in every annual statement. However, much less of this work is done than should be carried on. Thus in New York City, leaks totalling upwards of 200 m.g.d. have been located and stopped during the past ten years. As the cost of stopping such leaks is estimated at about $3 to $4 per m.g. saved, it is plain that a much larger force should be employed and the money spent on this work be substantially increased.

Systematic Operation of Valves and Systematic Inspection and Repair of Hydrants. These two items have been grouped as they are similar and each one adds to the annual cost of the distribution work if they are effectively performed. These are also good-housekeeping items, but with the hydrants, the important function of supplying water for fire protection is involved.

Meter Testing. In dealing with this subject, one must consider the primary use of the meter and the revenue derived from the water taken as shown by meter registration. If meters are not removed and tested except when the readings plainly show that something is wrong with the meters, the cost of operation is cut down. Much more than offsetting such saving in cost are the unfairness developed when some consumers pay for only a small part of the water drawn on their premises and the loss in revenue occasioned by meters running slow.

Meter Reading and Billing. A decrease in the time interval between readings and also between billing periods will decrease maintenance and operation costs but is likely to decrease collections and increase customer friction and ill-will.

Obsolescence and Lossin Carrying Capacity. These two items may be called depreciation or may not be included in the annual costs set up by water plants as attributable to distribution systems. They should, however, be reflected in the annual cost figures, and, if omitted, may make quite noticeable differences in the figures reported by various communities.

CLEANING AND LINING EXISTING PIPE LINES IN BUENOS AIRES

BY BRUCE HARKNESS*

[*Read February 16, 1939*]

It has been the writer's good fortune for the past six years to visit twenty-one different countries representing the Tate Processes as organizing engineer. During this period, several papers have been published on cleaning and cement-lining of water mains in position, the last one on the Tate method in this country being read by Thomas H. Wiggin before the American Water Works Association's meeting in September, 1935. This paper dealt with, and gave a description of work then being carried out for the Manchester Water Works Committee, Manchester, England. I am indeed pleased to have the opportunity of giving a paper on this same subject, and as I only returned from the Argentine a few weeks ago, after having carried out work there, I think that perhaps I might cover the ground very well if I were to give full detailed description of operations carried out in the city of Buenos Aires.

That branch of the Obras Publicas controlling the water supply of Buenos Aires, known as the Obras Sanitarias de la Nacion, first had demonstrations in their works yard in Buenos Aires on some 300 meters of a new 4- and 6-in. pipe line.

Whilst in the Argentine I was asked to visit the city of Parana with the object of studying the condition of pipe lines in the reticulation system, and giving estimates for the cleaning and lining of 65 miles of pipe lines from 4 to 12 in. in diameter. Some of these pipes (4 in.) had been cleaned by the O.S.N. in 1929 by means of a power scraper, and restored to 91% of their original carrying capacity when new; after 7 years, in 1936, these same pipes were again tested, and a loss in delivery of 65% was recorded. It was found necessary again to clean these pipes in December of last year, owing to the fact that they had again become badly choked. This is just one more experience in further substantiation of the fact that when a pipe is once cleaned, continued cleaning has to be resorted to if good results are to be maintained.

Later I was requested to return to Argentina to take charge of

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the first field work to be done in that country under the Tate patents. Buenos Aires gets its water supply from the Rio de la Plata, and the water is very soft and corrosive. It was my lot to inspect numerous pipe lines in different sections of the city, and I found that in every case where the pipe had been in service for 10 years or more, corrosion existed to a very marked degree. The Board of the Obras Sanitarias de la Nacion requested that the first field work be carried out in the Capital.

A section of the city was selected which was served by cast-iron pipe lines of 5-in. internal diameter. These lines had been laid some 23 years ago, and were badly blocked with tuberculated matter. When opened up, it was found that the diameter had been reduced to about 3 in.

At the outset, before describing the field work perhaps it would be just as well for me to give a description of the Tate cleaning machines. A cleaning machine is constructed for each size of pipe, and consists of a plurality of cast steel cutter-blades, which are mounted and housed intermittently and in such a manner as to overlap, so that any given point in a pipe line would be cleaned during one pull of the machine through the main. See Figure 1.

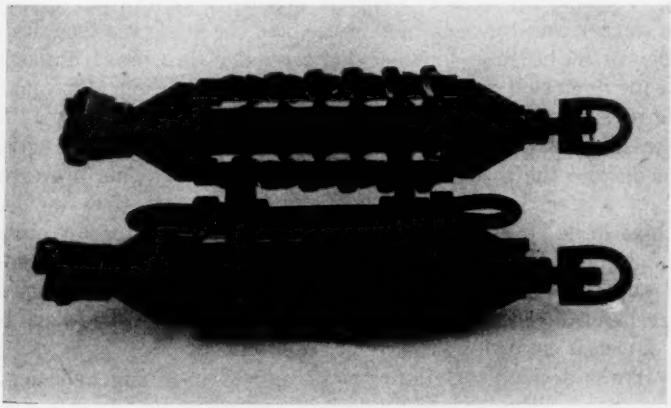

FIG. 1.—TATE CUTTER-TYPE CLEANER FOR 5-IN. LINE.

Two or more of these machines are used in tandem. The machine is usually hauled through the line by means of a special power winch mounted on the rear of a truck, and can be drawn through a badly incrusted pipe line at rates varying from 5 to 45 ft.

per min. As the cleaner is drawn through the line, each blade shaves off a layer of corrosion; this shaved matter falls through the center of the machine, which is designed to allow the cut corrosion to fall behind the cleaner, thus not allowing it to block the machine's progress through the main. This cleaner is capable of cleaning up to 1000 ft. per 8-hour day. In the absence of a power winch for this work, hand winches can be used.

The city of Buenos Aires is laid out in squares, each approximately 460 ft. by 460 ft., and the first section treated was one of these blocks. First of all a 3-in. auxiliary service pipe of galvanized iron was laid alongside the building alignment, and all ferrules were located, disconnected and fitted to this temporary service. The holes in the main were plugged with special plugs which were made to fit flush with the inner surface of the pipe. Branches were fitted with special cores, and all fire hydrant risers were fitted with special riser-plugs, which are tapered, so as to permit the mortar to flow under pressure and thus line the hydrant. Excavations were made at each end of the block, and 6-ft. sections cut from the main. Hand winches were then placed in position at these cuts. A cable, ⅝-in. in diameter was then threaded through the pipe line by means of steel rods. A Kennedy scraper was then pulled through, after which the Tate cleaner was drawn through twice, and the main was then flushed. A heavy steel brush and rubber plungers were then drawn through to clear the line of all remaining fine particles of corrosion. The amount of corrosion extracted from the main averaged approximately 12 tons to the mile. A prover between two rubber plungers was then passed through, and the main was then ready for lining. This prover consists of a steel cylinder, ⅛-in. larger in diameter than the lining machine to be used, and its purpose is to prove whether any obstruction has been left in the main. In cases where there are over-run lead joints in the line, the Tate cleaning machine will cut them out; I have known cases where as much as 27 pounds of lead have been cut out clear and brought out by this cleaner.

It was decided to line the main with ¼-in. lining, reducing the diameter to a little less than 4½ in., the pipe being originally a little less than 5 in. in diameter. (The nominal diameter was 125 mm.) A mixture of two parts of sand to one of portland cement was then prepared and water added until a slump of approximately 9 in. had been obtained. This slump varies for each size of pipe, for instance, for a 5-in. pipe, the slump is 9 in., and for a pipe of say 10-in. diameter the slump is 4½ in.

While the mixture was being prepared, a special loading tee was fitted to one end of the pipe line, and the cable was fastened to a closing gap on the loading tee. The mortar was fed into the main through a special hopper mounted on the riser of the leading tee; this was done by means of hand plunging, and no difficulty was experienced in getting the pre-determined quantity necessary for lining into the pipe line. This material filled the first 80 ft. of the 432 ft. of pipe being lined. When all the material had been plunged into the main, the hopper was taken off, and the riser blocked off with a blank flange. Next, the closing cap at the end of the loading tee was removed and the Tate lining machine was fastened to the cable, and pulled through.

The Lining Machine and Its Functions

The functioning of the dehydrating orifices in the spreader is a most important feature of the Tate lining apparatus (Fig. 2), and it

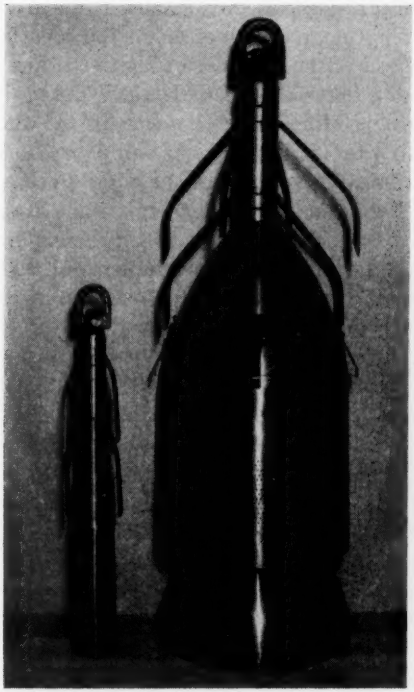

Fig. 2.—Tate Liners for 12 and 3-in. Pipe.

is to be noted that it is not practicable in this or any like apparatus, to follow the accepted practice in the mixing of cement. It is essential that only the exact quantity of water be added to the powdered cement to transform all the particles to a colloidal consistency of what might be termed this gelatinous state required to enable it to be pushed through the pipe by the spreader instead of being plastered on to the pipe walls thereby. Unless the correct consistency has been arrived at, the lining might be irregular. Should too much water have been absorbed in the dry mix, the squeezing action of the spreader would cause the water to travel ahead of the spreader into the absorbent and uncompressed mix in front of the spreader, resulting in premature dehydration of the mix.

To overcome these objections, and successfully operate the apparatus, the cement is mixed with an excess of water sufficient to destroy its power of further absorption; in technical terms, it is mixed to a specific slump for each size of the pipe being lined. With such cement, the spreader, as it is hauled through the pipe, readily and evenly spreads the cement mortar on the pipe wall. The water will not travel ahead of the spreader owing to the fact that the cement in front of it, being fully charged with water, functions as a buttress.

The dehydrating orifices enable a surplus of water to be used in the cement mass without adversely affecting the finished lining.

When the cement mass containing a surplus of water is fed to the pipe to be lined, and the spreader is hauled through, the soft cement is readily spread thereby. As the diameter of the tapered spreader increases, such cement is compacted so that the surplus water is squeezed out of the cement by reason of its greater fluidity as compared with the mass of compacted colloidal cement particles.

Theoretically, this surplus water, by reason of its great comparative fluidity, would immediately rush to the place of lowest pressure in its vicinity, which, of course, is around the nose of the spreader, where the pressure is much lower than in the compacted cement lining around the skirt. Actually, only part of this surplus water returns to the vicinity of the spreader's nose, owing to the damming effect of the bulk of cement ahead of the spreader. A large proportion of this water collects in the vicinity of the ends of the arms, at which the cement lining is insufficiently compacted to prevent the fluidity of the water from asserting itself. The water is thus allowed to squeeze to the surface of the cement now formed.

In practice it is found that some of the excess water around the ends of the arms becomes trapped between the skirt and the cement

lining. In a spreader without dehydrating orifices, this water would be forced back into the cement lining about the middle of the skirt owing to the increasing pressure; at the end of the skirt, the pressure—that is, the degree of compactness—would be great enough to prevent the water from returning to the surface, notwithstanding its fluidity, so that when the skirt has passed and the pressure has thus been reduced, the lining would be overloaded with water and slumps would be incorrectly proportioned.

The dehydration orifices, however, provide a low-pressure get-away for the surplus water immediately prior to the final smoothing of the lining, and before it has returned from the surface of the lining to the interior thereof. This water must, of necessity, carry a very small proportion of cement with it through the orifices, and these cementitious drippings pass out the end of the skirt onto the finished lining, which is so compact, dry and smooth, that the drippings do not have any effect thereon. The water runs away, any small amount of cement therein being lightly spread over the lining by the float.

The machine compacts the mortar on to the walls of the pipe at a pressure of approximately 130 lb. per sq. in., and the lining when completed is homogeneous in nature, and one of continuity; the branches, bends and all joints being lined. Thicknesses vary from ⅛ to ¾ in., according to the specified requirements.

After 12 hours the plugs in the service holes in the pipe line were removed and the cement blocking them, cut out, and the ferrules then restored. The branch and fire hydrant riser-plugs were removed, and the line restored to service after ten minutes of flushing.

One side of the square was approximately 80 meters (266 ft.) and this was scraped, plunged, and dried preparatory to lining in 1 hour, 50 minutes; whilst this was being done the mortar was prepared. Seven minutes were taken to load the mortar into the pipe line, and the actual time taken to line this length, that is the time for the lining machine to traverse the length of the block, was 12 minutes. One section consisting of 18 ft. of straight pipe and two 45-degree bends was lined in place; this was cleaned in 20 minutes and loaded and lined in 5 minutes.

Twenty men started on the work, but on the second day, this number was reduced to thirteen, in addition to the foreman. The main varied in depth from 3 to 6 ft., and was laid in loam-clay type of soil, under the sidewalk which was of pre-cast concrete slabs set in cement mortar.

House connections were on an average of one every 18 ft. Complete cost for cleaning and lining, including excavation, all pipe work, installing auxiliary service, reconnecting, resurfacing, depreciation and all overhead charges, worked out to one-fourth of the cost of complete renewal.

Flow tests were taken with the following results:

1.	Before cleaning	97 g.p.m.
2.	After cleaning and before lining	287 g.p m.
3.	After lining	261 g.p.m.

All tests were made at midnight under identical conditions, and the final results were excellent, considering that the lining in this 5-in. pipe was ¼-in. in thickness. Normally this should average about ⅛ to 3/16 in. in thickness.

Coefficients of flow—Williams & Hazen—calculated on actual diameter within the lining, on 5-in. pipes in England were found to be 157.

New pipes first laid and then lined in sections of say 500 ft. or more at a time compare very favorably in cost with that of shop lined pipes, with the unquestionable advantages of lined bends and specials, and the elimination of risk of corrosion at pipe-joints. All joints are filled with the cement, which means one continual pipe line. Another great advantage is that all risk of damage in transit is eliminated, and perfect curing of the lining is effected under water.

Discussion

Thos. H. Wiggin.* Mr. Harkness mailed me a copy of his written paper which I have read with interest. I will not undertake to discuss the work at Buenos Aires which I have not seen, nor to discuss the intricacies of the dehydration caused by the perforated skirt, though I have heard the inventor, Mr. Wm. T. Tate, explain the fact that only by the application of correct principles in designing this dehydrating skirt was he able to secure a compact lining which would adhere and to complete a useful invention.

I have little to add to my paper given before the American Water Works Association in 1935[1] recounting my observations made in Manchester, England, in 1934, where for a period of about a month I observed the practical application of the Tate process in the Manchester Water Works distribution system. The New England Water Works Association would not wish a lengthy repetition of that paper,

*Consulting Engineer, New York, N. Y.
[1]Jour. Am. Water Works Assn., Aug. 1935, p. 1073.

but since engineers and operators are too busy to read much of the engineering literature which comes across their desks and since my former paper was published nearly four years ago, this meeting may be interested in a summary of my findings even though it is largely repetitive.

I found that the Tate process was being used regularly under a contract between the Manchester, England, Water Works and the English Tate Company in distribution pipes 3, 4, and 5 in. in diameter, which were so filled by incrustation caused by the very soft water that the area of the water-way was reduced to half or less of its original size. This work was being done at a profit for a small fraction of the cost of new pipe lines. The officials of the Water Department were well pleased with the results and the people along the route were likewise pleased and showed it in my presence by their friendly attitude toward the pipe-lining crew.

It took only parts of two days to clean and line the pipe in a city block. The actual lining was done at a speed of about 20 ft. per min. as timed by me, so that this part of the process took but 10 or 15 minutes to the block.

The resulting lining has a flat place in the bottom, giving a slightly horse-shoe shape, owing to the settlement, in the invert, of the softer part of the mortar squeezed through the perforations in the skirt. Yet, after hardening, this flat part of the lining did not seem noticeably different from the rest of the section as seen in a cross-section cut through the pipe and lining.

The Water Department at Manchester kindly allowed me to direct their first flow test to obtain the coefficient of the lining, and themselves made, after my departure, additional tests the results of which were supplied to me. The full table of those four tests is short and I will repeat it.

It will be seen that the character of the surface of the lining

Pipe Diameter Inches	Coefficients of Flow (Williams-Hazen) Calculated on Nominal Diameter of Pipe	Calculated on Actual Diameter within Lining
3	63	148
4	88	152
5	97	142
5 (another stretch)	97	157

was excellent since the coefficient reckoned on actual diameter was very high, viz. 142 to 157. The coefficient reckoned on the nominal diameter of pipe was relatively low for small pipe and higher as the size increased because of the varying percentage of the cross section of the pipe occupied by a lining about 5/16-in. thick. In pipes of still larger size the coefficients reckoned on the nominal diameter would be well above 100. Thus if a 12-in. pipe having a bore of just 12 in. were lined down to 11½ in. with a lining having the character of C=145 for actual diameter, then its coefficient reckoned on the nominal diameter would be 130.

It should be said that all coefficient measurements were made by a method first used in such cases by the late Bert Hodgman, viz. with a piezometer pipe laid parallel with the main for the whole length under test so as to bring the heads at the termini of the test stretch to the same U-tube where loss of head was measured accurately by a scale without the error of spring pressure-gauges. The quantities of flow were measured by a tested meter.

I saw yard tests on 6, 9 and 12-in pipes in stretches of 100 ft. or more. The results were excellent. These tests were practically the same as tests of pipe buried in the ground. Some of these tests were varied at my request to try extreme curvature made by opening joints on one side and in other cases by putting in reverse curves using a pair of 1/16 bends. The curves made with pulled joints in straight pipe were lined successfully with the ordinary straight-line-mandrel, and the whole 100 ft. of pipe, containing an offset made with 1/16 bends, was excellently lined with a bend mandrel. I also saw tests made in this country a year ago by Mr. Harkness which showed the same good results as those made in England.

Like all processes of applying mortar lining to pipe, the quality of the cement and of the sand in relation to the permanence of the lining is worthy of more care than is generally being given to these matters. Probably cement of low solubility should be sought. This will make for longevity and freedom from caustic water which is sometimes experienced with cement linings. The cost of the cement is practically negligible in the process, and no pains should be spared in obtaining the most permanent cement to be found. Tests are needed of cements for all the cement linings now so commonly employed.

RECONDITIONING LARGE WATER MAINS

BY H. SEAVER JONES*

[*Read February 16, 1939*]†

To round out the subject upon which Mr. Harkness has so interestingly discoursed regarding reconditioning by the Tate Process of the smaller sizes of pipe, it might not be amiss to say a few words with regard to somewhat similar reconditioning, that is the cleaning and lining with cement of larger sizes of steel and cast-iron pipe, 36 in. in diameter and upwards.

A noteworthy feature of this large-diameter field is its immensity. Fairly accurate records are available of existing old steel mains. Possibly the earlier skepticism regarding their longevity resulted in their being indelibly recorded. To compile a similar record of cast-iron pipe is more difficult. The comparable, total footage of cast-iron pipe is probably three or four times that of steel, though the distribution from the standpoint of diameters would find the average size of cast-iron pipe of a considerably smaller diameter than that of steel pipe, but the average age of the cast-iron pipe would be greater, certain lines dating back 80 years.

As William W. Brush, in an article entitled "Reconditioning Large Water Mains" which was published some time ago, recommended the reconditioning of pipe lines after 20 to 30 years of service, the following canvass of steel mains in the United States has been grouped into three periods, and installations of less than 20 years' service are not included.

Municipal steel mains only, 36-in. in diameter and upwards	
20 to 30 years in service	1,015,458 ft.
30 to 40 years in service	909,144 ft.
40 years and over	985,509 ft.
Total	2,910,111 ft.

There are, therefore, about three million linear feet of municipal steel mains that have been in service from 20 to 60 years, of which 1,480,000 ft., or almost half, fall within the diameters of 37 to 49 in. We can conservatively estimate, therefore, that combined there are over 12,000,000 linear feet of municipal steel and cast-iron water mains

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†See preceding paper in this JOURNAL.

36 in. in diameter and upwards that have been in service from 20 to 80 years.

As it was the report of the Committee on Pipe Line Coefficients of the New England Water Works Association that jolted the engineering world into the realization: (1) that the actual carrying capacity loss of pipe lines after 30 years was 20% worse than the hitherto generally accepted loss predicted in the Hazen-Williams tables; (2) that an average coefficient of 87 had been reached in 13 instead of 30 years, and (3) that in many districts thoughout the country coefficient values ran as low as 40, 30, and in some instances 20, no further time need be taken to stress the significance of these determinations nor their very great bearing on the subject of reconditioning pipes. The application of these facts in actual practice means just two things in relation to these old pipe lines; (1) that the anticipated volume of water is not being delivered; and (2) that where force mains are involved, the pumping cost is excessive. It is usually the restoration of carrying capacity that constitutes the primary reason for reconditioning. Frank Barbour once sagely remarked that "the value of a pipe line is measured by its hydraulic usefulness and not by its life as a metallic structure." Nothing could more comprehensively sum up the subject in fewer words. The only excuse for a pipe is water, and, for the selection of a specific diameter of pipe, a definite and constant volume of water. This constant volume, or maintenance of capacity, can now be reasonably assured with the better coatings and linings for new pipes and can be recaptured for old mains of deficient capacity by reconditioning. At the same time, that "life as a metallic structure", which not so long ago was the bugaboo of the steel-pipe salesman, will secure its share of attention, if any is required, as spot welding, structural reinforcement and necessary general repairs would naturally be contemporaneously undertaken at the time of reconditioning.

The first step in reconditioning is the cleaning of the pipe line. This process of cleaning, which is so well understood as to need little clarification, is usually accomplished by a cleaning machine inserted in the pipe and motivated in its course throughout the line by a controlled water pressure. The National Water Main Cleaning Company has successfully cleaned by this process mains 48 in. in diameter and believes its particular equipment and method equally applicable to pipes 60 in. in diameter. After cleaning, different protective materials —paints, enamels, and cement applied by various methods—have been utilized at times on the interior of mains to perpetuate the benefits

of cleaning. In preparation for any treatment, a certain amount of subsequent hand cleaning is usually required, especially around rivets and seams on old steel mains. This work is cut to a minimum where cement is utilized as the pipe does not have to be meticulously clean to receive a cement lining, nor does it have to be perfectly dry, as it does for paints or enamels. Ordinary sweating of the pipe interior, which has to be guarded against in the application of some materials, is an advantageous concomitant where cement is being applied.

The centrifugal method of applying cement lining to pipe *in situ* embodies certain advantages and many unique features. The process is adaptable to pipe diameters of 36 in. and greater. The equipment used in this method consists of two groups, the mixing and power plants located on the ground level and the feeding and lining apparatus operating within the pipe underground. The most important device is the lining machine, a centrifugal apparatus equipped with two electric motors, one for traction with a variable speed transmission, the other of constant speed driving a short screw-feed conveyor, the mortar lining head and a set of slowly revolving finishing trowels. As the mortar passes through the ports and into the distributing head, it is thrown against the pipe wall by radially spaced high speed vanes that rotate outside of these fixed ports, at a speed of 1,000 r.p.m. The trowels are so designed and adjusted that their curved surfaces smooth and finish the lining after placing. The travel speed of the lining machine can be so slowed down that thicknesses as great as may be desired can be obtained and so speeded up that thicknesses of any desired minimum will be created. The application of a cement lining by this centrifugal method insures a dense, homogeneous, smooth lining of the desired thickness throughout the interior of the pipe. The use of centrifugal force as the impelling medium, and the elimination of air entrainment, means that the mortar, with its low water ratio, exactly as mixed above the ground, is transferred to the interior pipe wall with no accompanying rebound or even spattering.

One of the Newark, N. J., jobs might well be cited as typical of reconditioning accomplishment. The first contract at Newark of this character was for cleaning and lining with cement 27,000 ft. of 48-in. riveted-steel main that had been serving the city uninterruptedly for 40 years. Over 105 tons of tubercles and incrustation were removed from this length of pipe line. Before the cleaning was undertaken, the flow of the line showed a coefficient, C, of 70 in the Williams-Hazen Formula. When the pipe was new, the coefficient was about

110; after cleaning was completed, the coefficient was found to be 110 again. After the installation of the cement lining, it was found that C had increased to 124, or 12% greater than the original carrying capacity of the pipe 40 years previously when it had been put in service, new. While the cement lining was placed to protect the steel from further corrosion and deterioration, it actually added over 10% to the value of the pipe line as compared with the pipe when new, since one is buying capacity when installing water pipe. There is, of course, the added valuable advantage of preventing in the future the formation of tubercles, the gradual destruction of the pipe wall, and reduction in capacity. As *Water Works Engineering* expressed the situation editorially, "The making of this Newark line 'better than new' after 40 years of service, is a noteworthy achievement in the water works field."

In reconditioning old mains, where there is ample opportunity for inspection of the interior during the various stages of the process, many curious conditions are revealed, some of which naturally raise certain questions. It is well nigh impossible to determine the condition of the interior of a main, that is the depth of pitting, deterioration of metal, etc., until a careful examination is made of the metal after cleaning. As a result of this examination, the proper thickness of cement to be used is determined. On this first Newark contract, the condition throughout the greater part of the line warranted the use of ¼-in. cement thickness, in certain sections a thickness of ⅝-in. was utilized, and on others a thickness of 1-in. was deemed advisable.

From observation, there seems to be little difference between the interior tuberculative tendencies of steel and cast-iron pipe. In the old lines, both types under similar conditions seem to have been equally vulnerable.

Several problems have naturally presented themselves from time to time in the working out of this process. The matter of bond between the lining and the pipe wall is of negligible importance. It has been proved that a cement lining almost loose enough to rattle, becomes to all intents and purposes bonded to the pipe after being put in service. We find this fact practically corroborated by Thos. H. Wiggin, who stated in *Water Works and Sewerage* (September, 1933): "I have never been particularly afraid of a small amount of looseness in the lining because I have felt confident that it would do what all cement structures do—swell when soaked." The matter of curing was one that caused, at first, no little concern. This was finally solved simply and effectually. The satisfactory lining of couplings

appeared difficult of accomplishment and at first caused trouble but as this centrifugal method of applying cement mortar lining is equally adaptable to new pipe, after the line has been tested and backfilled, and as couplings fill an important position in modern pipe engineering, it was necessary to conquer this problem also, which was finally done.

In consideration of the excessively heavy thicknesses of plate that seem, in recent years, to have crept into pipe specifications, it is interesting to note that practically all the old riveted-steel mains held up as examples of longevity and now rounding out a half century of heroic service, are of ¼-in. and 5/16-in. plate thickness with a maximum of ⅜-in. in some cases. One can't refrain from raising the question whether, in the light of this service, doubling the cost of steel pipe by the use of greatly increased plate thicknesses is justified; particularly since present-day coatings and linings are far superior to those utilized on the old mains.

A brief word as to the history of cement-lined pipe. Throughout New England and the Atlantic Seaboard are found many old lines dating back 40 to 90 years, consisting of a light diaphragm of steel or wrought iron, lined on the interior with cement and frequently surrounded on the exterior with the same material. Most of these mains are now obsolete for various reasons, principally due to the fact that present-day water pressures far exceed those for which the lines were intended. The splendid condition of these old mains is the extraordinary thing about them. They have carried their volume of water throughout the years with practically no diminution of quantity. They have protected the metal of the thin, underlying diaphragm from even a vestige of corrosion, despite a certain amount of leaching in some cases. If these old-time cement linings have given such remarkable service, is it not reasonable to suppose that a present-day, well-burned cement of low solubility and of selected chemical constituents, carefully screened and of far greater density, should afford a period of at least equally satisfactory service? As Leonard Wood, in the December 1933 *Journal* of the American Water Works Association stated: "The better linings have increased the sustained carrying capacity for tuberculating waters by 20% to 100%. Of these better linings no other can yet show as long and successful a service record as cement. In one or another kind or water works pipe, cement linings have been in constant use since the first cement-lined sheet-iron pipe was laid in Jersey City in 1845."

In summarizing, with regard to reconditioning of pipe lines it might be stated:

1. That the cleaning and re-coating of unlined pipe is desirable at the end of 15 to 20 years of usage.

2. That the restoration of original carrying capacity can be accomplished at a reasonable cost by the application of a thin cement lining that will, at the same time, extend indefinitely the useful life of the pipe.

3. That the original carrying capacity cannot only be restored but indefinitely sustained.

4. That steel or cast iron will not corrode or tuberculate when protected by a cement lining.

5. That the pipe surface does not have to be dry at the time of application of the cement.

6. That the pipe surface does not have to be as clean for the application of cement as for other materials.

7. That no danger from fire or silicosis exists in the application of cement linings.

8. That no precautionary ventilating of the pipe line is required in the application of cement.

9. That a cement lining application speed up to 4½ linear feet of pipe per minute permits the complete reconditioning of many lines that can be spared from service for only brief intervals of time. (On the last reconditioning job, 21,000 ft. of 48-in. pipe were cement-lined in 25 working days, operating one eight-hour shift only.)

10. That the entire reconditioning cost, cleaning and lining with cement, can be accomplished for a small fraction of the cost of duplication of the pipe.

SAFEGUARDS FOR GROUND-WATER SUPPLIES

BY LESLIE K. SHERMAN*

[*Read March 16, 1939*]

Wells are important sources of water supply in Connecticut as in all other parts of the world. Fifty-two water supplies, classed as public, derive water wholly or in part from wells in Connecticut, with a great many more factories and semi-public systems dependent on ground water. In spite of the large number of wells of all types supplying water of satisfactory quality, there are occasional wells that cannot be considered potable supplies. It is desirable to learn when possible, why these wells are unsatisfactory in order that detrimental conditions may be avoided in the location, construction, or protection of new wells or remedied, if possible, in existing ones.

Location

The first consideration in well development is the selection of a suitable location. It is important to choose a site removed as far as possible from sources of pollution as it is not possible to set any definite distance from a source of pollution as safe. The Report of the Committee on Ground Water Supplies of the Conference of State Sanitary Engineers has suggested 50 ft. as a minimum for ideal conditions and 300 ft. if the source of contamination is above the well. These figures are, of course, no guarantee of safety.

Such sources of pollution as cesspools and privies are usually given adequate consideration when locating wells, but nearby sewers are sometimes overlooked or believed to be tight. Sewers may not remain tight and are always potentially dangerous. A case of pollution from a broken sewer line occurred several years ago at a Connecticut institution. A large dug well, properly curbed and covered, had furnished a safe source of water for many years. Periodic bacteriological examinations had been satisfactory but suddenly showed the presence of coliform organisms. Investigation revealed a sewer line about 50 ft. from the well. Chlorination was instituted and the sewer excavated. It was found that the sewer line close to the well had been constructed of iron and was still tight. A break had occurred in the tile pipe beyond the iron section. While this was slightly

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higher than the well, the pollution had to travel about 90 ft. through sand and gravel. This shows the uncertainty of natural filtration. The engineer of the institution introduced an element of humor, and perhaps more, by carefully repairing the sewer and then dumping stable manure around the pipe to prevent freezing. After the break was repaired, chlorination was continued on a permanent basis.

The Wisconsin Well Drilling Rules state that "no sewer or drain located underground, shall be installed within twenty-five feet of any existing or proposed well, unless constructed of cast iron pipe with leaded joints in which event a minimum distance of ten feet shall be maintained." It will be noted that the case of pollution cited occurred with a much greater intervening distance. The recommended separation of 50 ft. in the report of Committee on Ground-Water Supplies of the Conference of State Sanitary Engineers is also less than in the particular case mentioned.

Careful attention should be given to the possibility of flooding of wells by streams. There is always a temptation to locate wells at low elevations in stream valleys in order to get the maximum possible water yield. The hazard of flooding is thereby increased. Protecting the well proper from flood water may not be sufficient to insure safety. Two cases of pollution in this manner come to mind. In the spring of 1936 the back water of the flooding French River in northeastern Connecticut, for a very short time, reached the curb of a dug well of a small water company. No river water could have entered the well directly. However, it was thought advisable to chlorinate the well immediately. Samples for bacteriological examination were collected as soon as possible. Contamination was indicated, and additional samples continued to show coliform organisms in the untreated water for several months. Permanent chlorination equipment was then recommended and installed. A more recent case is the contamination of a drilled well in Ansonia used as a semi-public supply in a tenement district. Flood water, made up of city storm drainage, including some sewage, and water from the polluted Naugatuck River approached this well within about 50 ft. on two sides in September, 1938. Samples revealed bacterial contamination which could not be eliminated by repeated hypochlorite treatments. After three months, the samples were once more free of coliform organisms, and the well was again placed in service. Fortunately, the public supply was available for use during the emergency.

At a comparatively new state hospital the water supply is obtained from several 6-in. driven wells. When the supply was placed

in use, the grading around the wells was not completed due to lack of funds. Coliform organisms in the well water were eventually traced to two wells close to a depression containing standing water. It was said that pumping on these wells, quickly but only temporarily, removed the surface water. In any event, filling the low area and raising the ground surface around the wells above possible flood level apparently eliminated objectionable bacteria.

Construction

Fundamentally, the object of any type of well construction is to permit the entrance of water from strata bearing potable water and shut off water from all other sources. The method of accomplishing this objective varies with the type of well.

Dug Wells. The simplest and most common type of well is the dug well. Wells of this kind may be quite satisfactory when properly located and are sometimes capable of providing large yields.

Dug wells should be protected by a water-tight curbing and casing, the latter being made preferably of concrete and 10 ft. in depth. Numerous satisfactory wells are in use, however, with casings less than 10 ft. in depth, although 6 ft. is probably the minimum consistent with safety. The curb and casing should prevent the entrance of any inadequately filtered surface water.

The top of a dug well should be a tight concrete slab keyed to the curb, or the curb should extend well above the ground surface and a superstructure or roof provided adequately to prevent the entrance of any foreign matter. Attention is also called to the necessity for providing manholes or hatchways with curbs and overlapping covers to insure water-tightness. Wooden manhole covers and frames are subject to rapid deterioration and must be well maintained. Usually, the covers are made with tongued and grooved planks, or the wood is covered by watertight material.

Any overflow pipe or ventilator should be screened with a fine-mesh material to keep out rodents, reptiles, and so far as possible, insects. Rodents and reptiles, either alive or dead, are often found in wells not protected against them.

Cases of dug well pollution due to faulty curbs and covers are too numerous to require specific mention.

Driven Wells. Driven wells require tight casings down to the water-bearing stratum, where some type of screen is provided. The screen design is of utmost importance in order that a satisfactory water be obtained, and many factors should be studied, such as inlet

velocity and particle size of the water-bearing material. However, screen design is not within the scope of this paper.

Whether a simple well point or more complicated type of strainer is used, it is essential that care be taken to prevent surface water following down the outside of the casing to the screen level. Grouting around the casing and construction of a concrete collar around the top of the well is desirable. Joints between pipe sections should be made tight.

The usual methods of pumping from wells of this type, i.e. by suction lines to the casing tops, or by turbine type pumps, provide in most cases adequate protection at the tops of such wells. Any underground suction pipes should be absolutely tight to prevent drawing water near the ground surface into the lines, and they should not be located too close to nearby sources of possible pollution.

Drilled Wells in Rock. Drilled wells, frequently called "artesian wells" whether they actually are or not, are considered by most people to be the safest ground water supplies. The limited yield and the difficulty of estimating the cost of drilled wells in New England have generally restricted their use to small public and private supplies.

Where wells are drilled in such rock as limestone, pollution may sometimes travel long distances through crevices in the rock. In Connecticut, such long-distance travel of pollution to drilled wells is unusual. However, in spite of the common belief of the safety of drilled wells, slip-shod construction may permit contamination. After the well is completed, faulty construction below ground cannot be seen. Deep wells drilled in rock may be subject to many of the pollution hazards of shallow wells unless the casings are tight. The metal casings should have tight joints. The annular space between the casing and the excavation line should be filled to prevent water flowing down the outside of the casing. Cement grout, mortar, clay or asphaltum may be used to fill such space.

When the well extends into solid rock, the casing is generally omitted below the rock. The size of the drill hole is reduced after entering the rock, thus forming a shelf on which the casing rests. It is at this point that special care must be taken to seal the metal casing to the rock. This seal may be made with cement grout or special lead or rubber packers.

Most deep-well pumps must be located directly over the casing, but if a shallow-well type pump or some of the newer types of deep-well pumps are to be used, the well may be capped at the top and the suction or drop pipe cut through the side of the casting. The opening

through the casing should be carefully made and sealed to prevent the entrance of water at this point.

Probably the most common weak point in the protection of drilled wells is at the casing top. The annular space between the casing and the drop pipe is all too frequently left open. This opening permits the entrance of dust, dirt, grease and oil from the pump, packing leakage, and condensation drippings. While the foreign matter just listed may or may not carry any pathogenic bacteria, coliform organisms are very frequently reported in samples from open-top wells.

A number of seals are available to seal well casings at the top. Most of these are made in bolted sections which force packing against the casing and drop pipe. Vent connections are provided to which small vent pipes can be connected and extended well above the floor level. In some cases a substitute method of closing this opening has been the provision of a sheet-metal cap clamped to the drop pipe and extending out to and down over the well casing. This cap can be made dust- and drip-tight if not actually water-tight.

The importance of such caps has been frequently demonstrated. A number of examples were afforded in Connecticut at the Civilian Conservation Corps camps in the earier days of their operation. Most of the drilled wells at these camps were not provided with caps. Satisfactory reports of bacteriological examinations were not obtained until caps were provided. Monthly samples were submitted to the State Health Department from these camps. Occasionally, a poor sample would be reported, and upon investigation the writer would find that the well cap had been removed to make repairs on the pump.

Pump Stations

Well protection extends beyond the well proper to include the housing of equipment essential to the use of the well.

Pump houses should preferably be above ground, or if on a side-hill, part of the floor should be above the ground level and the door should be on the side above ground.

The pump house floor should slope away from the well casing or suction pipe, and an adequate floor drain should be provided. This drain should be tight and carry any drainage away from the well. It should, under no circumstances, permit back flow of surface or ground water into the pump house.

Leakage from pump packings may sometimes be appreciable in

quantity and must be cared for properly. Most pumps subject to this leakage are designed to collect this water at the base, and a drain connection should carry the waste water from the top of the well. This drain connection is frequently omitted, thus permitting the leakage to collect at the top of the well.

Some Cases of Well Water Quality Adversely Affected by Natural Materials

Substances adversely affecting well water quality are commonly considered to emanate from man-made sources. Thought must be given, however, to the possibility of abnormal conditions resulting from natural causes. The following cases are considered by the writer to be of interest.

Some years ago, a Connecticut water company constructed a large dug well about 30 ft. in diameter, and 30 ft. deep. This well was never approved by the State Health Department because the water was quite highly colored, had an objectionable taste and odor and contained coliform organisms. Recently, a gravel-packed well has been put down about 40 ft. from the dug well. The water from this well is of good quality. The well log afforded an explanation of the difference in water quality. The dug well took water from bog material whereas the new well is tightly cased through this material and a layer of clay below and takes water from a stratum of gravel below the clay.

In a town in northeastern Connecticut, the State Highway Department relocated a highway and in so doing was required to do considerable regrading of some private property. In the area regraded was a dug well which had been in use for many years. While not properly protected, from a sanitary standpoint, the well apparently had furnished water of a satisfactory physical quality. After the regrading, the residents complained of the taste of the water and stains on laundry. Upon inspection, it was found that the material used for regrading was a reddish sand, a typical iron-bearing material. Considerable material of this nature had been placed about the well in order to prevent direct surface drainage. Surface water leaching through this iron-bearing fill could enter the well through the loose stone curbing and walls and so carry dissolved iron into the well.

Laboratory analyses also indicated this to be the case. The following table shows some of the constituents reported:

Test	Tap Sample*	Well Sample*
Color—apparent	140	240
Color—true	55	160
Turbidity	7	30
Iron	48	20
CO_2	140	90
Solids	200	140
Fixed	120	85
pH	5.8	5.7
Alkalinity	62	30
Hardness	68	36

Organic constituents somewhat high.

*Figures are in parts per million, except pH.

It will be seen that the color, iron, and carbon dioxide figures are excessively high. It is interesting that the application of a vacuum to the samples in the laboratory removed sufficient CO_2 to raise the pH to 7.0. The difference between the two water samples was probably due to the fact that the one from the well was taken at the water surface while the pump intake was at a depth of about 10 ft. Storage was not a factor as no tank was provided, the automatic pump operating each time water was drawn.

The tests of the fill showed a high iron content and that some of this iron was readily soluble: 3.2% iron by weight (dry basis) were extracted with dilute hydrochloric acid and 3.6 p.p.m. of iron were dissolved in water in forty-eight hours. The well was finally abandoned. A new well was dug nearby. This new well was provided with a tight concrete curb and casing that extends into the natural soil. While the surface material was not changed, the iron-bearing water was prevented from entering the well, and a water of satisfactory physical quality is now obtained.

Numerous dug and driven wells in the Connecticut River Valley show abnormal chemical analyses, although apparently not dangerous. Nitrate figures of between 10 and 30 p.p.m. are common for samples from these wells. The most probable source of the nitrates is the soil of this territory which has been very heavily fertilized for a great many years of tobacco farming.

There have been cases of well water being unfit for use because of objectionable odor, in several Connecticut towns and cities. Hydrogen sulphide has been reported in well water in Hartford, Berlin and East Haddam. A garlic odor was reported in water from two different East Haddam wells. The odor of gas similar to illuminating gas

has been objectionable in well water in Willimantic and Wilton. In none of these cases was it possible to discover the source of the odor, and it may be assumed that natural materials were responsible.

Analyses of Well Water

After the construction of a new well is completed, the safety of the water obtained should be checked by laboratory analysis. Frequently, a new well will show bacterial contamination. Temporary chlorine disinfection may be needed to eliminate pollution introduced during construction. Samples should not, of course, be collected after disinfection until all trace of the disinfectant has disappeared.

Chemical analysis is of great value in giving a general picture of the sanitary condition of the ground water. It is not uncommon to learn from the chemical analysis that no gross pollution of the ground water exists, which may suggest that temporary bacterial contamination can be removed by temporary disinfection or improvements in the methods of protecting the well.

Periodic analyses are also important, as any changed conditions will be revealed. Some of the cases of contamination of wells cited previously were discovered by such periodic analyses.

Summary

The development of satisfactory safe ground water supplies requires care in the selection of the well location, proper underground construction and adequate protection at the ground surface.

Wells should be located as far as possible from all sources of pollution, including flood waters, and the uncertainty of filtration through natural materials should be realized.

Curbs and casings must be adequate to prevent the entrance of surface water. Care should be exercised to insure the exclusion of all foreign matter at the top of the well.

Pump houses should be so constructed as to be dry and readily accessible at all times.

POSSIBLE POLLUTION OF PRIVATE WATER SUPPLIES

BY ERNEST J. SULLIVAN*

[*Read March 16, 1939*]

This paper has been prepared with the thought in mind that many water department officials have been called upon from time to time for advice relative to the location and protection of private water supplies in communities where a public water supply system is not available. The writer realizes that in dealing with a subject of this kind more or less repetition may take place, but he has endeavored to deal more particularly with specific instances than to cover the subject in a general manner.

It might first be well to define the term "pollution" as used throughout this paper. This term will not be confined to the quality of the water as regards its bacterial count and effect upon public health but will be used in a broader sense to cover also the physical qualities such as appearance, odor and taste.

It is probably safe to assume that in colonial days all ground water was safe for domestic consumption, but with the increase in population and subsequent necessary sewage disposal, ground water supplies located in thickly-settled areas soon became contaminated and unfit for domestic use. Many of our present-day cities, such as Boston, Lynn, Lawrence and Lowell, maintained wells from which people living in the vicinity obtained their water supply, and naturally most of these wells were located in thickly-settled sections of these communities.

We should be justly proud of the foresightedness of the city and town officials who preceded us when we consider the early date that some of the public water supplies in this Commonwealth were established. Yet in many communities, not so many years ago, the town pump was a municipal necessity and was maintained in the same manner as the town hall and fire station. Many of these town pumps obtained water from sources which, to say the least, would be questioned under our present-day code of classifying safe water supplies. As civilization advanced, the American public as a whole demanded a water of higher standards. Today they demand a water which, in physical qualities at least, must be superior to the physical qualities of the water used during colonial times.

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We have all heard it said that "a well is a well", but I hope to prove that there is a great deal more to establishing a water supply, the water from which is to be used for drinking and culinary purposes, than to penetrate the earth's surface and obtain a liquid that, to all appearances, is a safe water to drink. When we stop to consider what a safe water, which is one of the essentials of life, means to us and the disastrous effect of an unsafe water, I believe that the obtaining and protection of such an essential is apparent.

Human nature is apparently so frail that, through thoughtlessness and generally not from lack of knowledge, many sources of water supply, which are naturally of good quality for human consumption, are contaminated either by improper protection from the entrance of surface drainage and foreign matter or by the disposal of sewage into the ground in the vicinity of the supply.

Generally, but not always, the two greatest factors in the pollution of water supplies can or could have been eliminated with very little added effort and expense. Probably the most important feature in planning or constructing a hospital, home, school or camp, where a private water supply and sewage disposal works must be established, is to obtain the water supply first and then to dispose of the sewage in such a manner that there is no possibility that the source of water supply will become contaminated.

Appended are copies of the results of the analysis made in connection with the various examinations referred to in this paper.

One interesting case is the quality of the water of a spring located in the limestone section of the state, the water of which has a constant temperature of 78° F. the year around. This spring is located in a wooded area remote from sources of pollution and is adequately protected by a water-tight curbing and cover. The water as shown in the analysis entitled "Spring A", while naturally hard, is low in organic matter, clear, colorless, free from bacteria characteristic of pollution and safe for drinking. The temperature of this water is no doubt due to its passage through the limestone formation before it reaches the surface of the ground, and while the temperature of this water would to most of us make it unpalatable and objectionable for drinking purposes, it might be an ideal water supply for a clubhouse or a health resort for showers and bathing purposes.

Another spring used as a source of water supply for a country school is located in a wooded area on the slope of a hill. It was adequately protected from the entrance of surface drainage, and there were no sources of pollution in the immediate vicinity. The

results of the analysis of a sample of water collected directly from the spring and entitled "Spring B" show that the water contained 15 p.p.m. of nitrates, was hard but free from bacteria characteristic of pollution. Another sample of water collected from this source three years later and under the same title showed that the quality was practically the same. A thorough examination of the locality revealed that a large area on the slope of the hill above the spring was used for agricultural purposes, and an investigation disclosed that during certain seasons of the year a large amount of commercial fertilizer was applied to this land. While the drainage area directly tributary to the spring was relatively small, the results of the analyses indicated that the fertilizer used on the land above the spring no doubt affected the quality of the water.

Another interesting case is a dug well used as a source of water supply at a roadside stand in the southeasterly section of the state. This well is about 30 ft. deep, the walls of which consist of 36-in. tile pipe constructed with cement joints and extend above the surface of the ground. It is adequately covered, therefore excluding surface drainage and the entrance of foreign matter. There were apparently no sources of pollution in the immediate vicinity.

The results of the analysis entitled "Dug Well A" show that the water had a distinctly unpleasant odor, was high in iron, contained a slight amount of oil but was free from bacteria characteristic of pollution. From the physical examination these results were unusual. On further investigation, it was discovered that located about 30 ft. from the well was an abandoned pit, now filled with earth, into which drainings from automobile crank cases had previously been discharged into the ground. The water entering this well had become contaminated by the contents of this abandoned pit.

Another type of well is that in which the well itself or that part of the well from which water is obtained is in ledge. This well is located in a fairly thickly-settled camp area and was constructed by excavating a hole 3 ft. in diameter and approximately 7 ft. deep in ledge, the top of the ledge being about 8 ft. below the surface of the ground. In the excavated shaft were placed 2 three-foot lengths of 18-in. vitrified-clay pipe. The area between the pipe and the ledge was filled with concrete, and a cover of concrete about 12 in. thick was placed over the well. Extending through the concrete cover and to a point near the surface of the ground was constructed a chimney of 4-in. vitrified-clay pipe placed bell-end up, the joints of which were made water tight, and in this chimney or stack a 3-in. galvanized-

iron pipe was installed for the purpose of obtaining the water. The excavated area around the smaller pipe from the top of the ledge to the surface of the ground was carefully backfilled with clean sand and gravel. The nearest source of pollution was a cesspool located about 75 ft. from the well but at a point where the earth cover over the ledge was much shallower than that at the point where the well was located. When this cesspool was constructed, the lower part was also excavated in ledge. Within a radius of approximately 250 ft. of the well were 4 privies and 2 cesspools in addition to the one already mentioned, all of which were on the ledge although in ground lower in elevation than the ground in the immediate vicinity of the well.

In the construction of this well every attempt had been made adequately to protect it from the entrance of surface drainage, but no consideration had been given to the possibility of crevices in the ledge extending in the direction of the sources of pollution, whereby the water of the well might become contaminated. When this well was constructed, it was noted that the water entered the excavated hole in the ledge near the bottom and that the 18-in. pipe was placed over the larger of these veins. Shortly after this well was placed in use, it was noted that the water had an offensive odor. The results of the analysis of a sample of water collected from a hand pump by means of which the water was obtained from the well and entitled "Dug Well B" show that the water was grossly polluted and unsafe for drinking or domestic use. No doubt the contamination entering this well was from the sources in the vicinity, pollution entering the crevices in the rock and finding its way into the water entering the well.

Another poor selection of a well site was in connection with the water supply proposed for a boy scout camp. This well was of the dug type about 15 ft. in depth and terminating on ledge. The walls of the well consisted of 24-in. vitrified-clay pipe constructed with water-tight joints extending about 2 ft. above the surface of the ground surmounted with a cover of matched lumber, through the center of which was placed a pitcher pump.

The camp, which consisted of one permanent building and a number of tents, was located on a flat area which sloped abruptly toward a lake. At the foot of this slope and within 30 ft. of the lake, the well was constructed. Approximately 150 ft. from the well at an elevation about 45 ft. higher than the ground at the well was a cesspool. This area was underlaid with ledge, which sloped toward the lake. The results of the analysis of a sample of water collected

from this well and listed as "Dug Well C" show that the water was polluted and unsafe for domestic use. In this instance, the party responsible for the selection of the well site disregarded the fact that the area was underlaid with ledge which naturally sloped from the camp site toward the lake or from the cesspool to the location chosen for the well. This fact was very apparent as there were outcroppings in a number of places throughout the camp. As a matter of fact, the lake water in this instance was of better quality for domestic purposes than the water from the well.

We shall now consider a tubular well located in the vicinity of a marsh area subject to the flooding of sea water. The well, located on the top of a hill about 40 ft. above the surface and about 200 ft. from the edge of a salt marsh, consisted of a 6-in. casing driven through sand and gravel to a depth of 60 ft., terminating approximately 20 ft. below the surface of the marsh.

The results of the analysis of a sample of water collected from this well and listed as "Tubular Well A" show that it contained 1,050 p.p.m. of chlorides and a considerable number of bacteria characteristic of pollution and that it was unsafe for drinking. On the adjacent property was located another tubular well 12 ft. in depth located within 20 ft. of and about 10 ft. above the same marsh, and the results of the analysis of a sample of water collected from this well on the same date as the last mentioned sample was collected and listed as "Tubular Well B" showed no such chloride content and that the water was safe for drinking and domestic purposes.

There were no sources of pollution in the immediate vicinity of either of these wells, but sewage was discharged into the ground near the marsh. In this case, the deeper of the two wells extended into a stratum which was affected by the sea and polluted water from the marsh area, while the shallower well terminated above this stratum and was thus unaffected.

In another instance, a tubular well was constructed for the purpose of supplying drinking water to about 100 families in a newly-developed area. This land development, the streets of which were not accepted by the town, was in a municipality which had a public water supply.

The Board of Survey Laws, included in Chapter 41 of the General Laws, which are based upon Chapter 191 of the Acts of 1907 had been accepted by this town, and a town by-law made it illegal for this municipality to install water mains and sewers in this area until the streets had been accepted by the town.

This well was located within 20 ft. of a small pond in an area the greater part of which was ledge. The well was drilled to a depth of 238 ft. below the surface of the ground, rock being encountered at a depth of 6 ft. A 10-in. casing was installed to a point 27 ft. 3 in. below the surface of the ground and sealed at this point. A 6-in. shaft was then drilled through the ledge to the depth of 238 ft. A large amount of water containing considerable clay was pumped from this well, and numerous attempts were made over a period of 10 weeks to clear the well, but all attempts were unsuccessful. The elevation of the pond was approximately 8 ft. below the top of the well, and the maximum depth of the pond was about 10 ft. The seal placed at a point approximately 27 ft. below the surface of the ground was for the purpose of preventing any water from the pond entering the well.

The results of the analyses of samples of water collected from the well and from the pond listed under "Tubular Well C" would indicate that the quality of the two waters was different and that the water entering the well did not come from the pond. It is interesting to note that the yield of this well was 6 g.p.m. and that even after long periods of pumping the water from the well had the appearance of milk. This water was never used, and the well was finally abandoned.

Probably the most interesting case herein considered is the pollution of a tubular well by the disposal of waste products placed on the surface of the ground at a point about 1500 ft. from the well. The well was approximately 100 ft. deep, 90 ft. of which were in rock. The casing extended approximately 4 ft. into the rock and was sealed. Filter beds located adjacent to a swampy area and used for the disposal of waste products from a pharmaceutical plant proved to be the source of pollution. The waste products from this plant were discharged at interval varying from 2 to 3 weeks. A line of levels run between the well and the disposal area showed that the top of the well was approximately 10 ft. below the surface of the disposal area. Between the well and the disposal works was a large outcropping of ledge some 80 ft. in height and approximately 800 ft. in width, extending at right angles to a line between the two points.

There were no sources of pollution in the near vicinity of the well, but the water drawn from the well at certain intervals had a distinctly unpleasant and musty odor, and the results of the analyses shown as "Tubular Well D" did not indicate pollution from ordinary sources.

After a thorough investigation, it appeared that the disposal of waste from the plant already mentioned might possibly be a source of contamination. To verify this assumption, 100 grams of uranine dye were placed in a ditch near the edge of the disposal area. Sixteen days later traces of dye stuff were noted in the well water, and the following day a test skein of wool was dyed a pale yellow by water from one of the fixtures supplied with water from this well. Test skeins of wool were also dyed on the following 4 days. From the time the dye stuff was placed in the disposal area and for a period of 22 days thereafter one of the fixtures on the system was allowed to drip constantly. The results of these observations apparently establish a connection between the disposal area and the tubular well.

Another tubular well consisting of 6-in. casing driven to a depth of 200 ft. through sand illustrates the possibility of contamination by disposing of sewage in the vicinity of a well. The well was perfectly constructed and protected from the entrance of surface drainage and foreign matter, but a cesspool was located about 85 ft. from the well. The results of the analyses entitled "Tubular Well E" show the effects of the sewage disposed into the ground in the vicinity of the well, and although any seepage from this source of pollution had to pass through about 220 ft. of sand, the purification in this case apparently was not sufficient to eliminate the contamination.

Another interesting case was the source of supply for a proposed Civilian Conservation Corps Camp site. This well was located in a wooded area near the edge of a swamp and remote from any dwellings, and there were apparently no sources of pollution in the vicinity. The well was 6 in. in diameter and about 156 ft. deep, the greater part of which was in ledge. A 6-in. casing extended into the surface of the ledge and was apparently sealed. This well was originally constructed to supply water for the operation of an illegal still. The still had been located in a camp some 400 ft. from and on land about 40 ft. higher than the ground at the surface of the well. The waste products from the still and sewage from the camp were disposed of in two pits, and these pits discharged into a trench some 150 ft. long which extended along the side of the knoll on which the camp was located and at the nearest point about 400 ft. from the well.

The results of the analysis of samples of water collected from this well and entitled "Tubular Well F" show that the water had an unpleasant odor and contained a large number of bacteria characteristic of pollution. After a careful search, the disposal area, though fairly well camouflaged, was discovered, and the results of analyses

of samples collected indicated that the pollution entering this well was apparently from this disposal area, the effluent of which entered the well through crevices in the ledge.

It might be interesting to note that a pile of sand used by the State Department of Public Works for sanding the highways was the source of contamination of two dug wells located about 100 ft. away. Calcium chloride mixed with the sand to prevent freezing and to make the sand cut into ice had leached out of the sand into the ground and entered the wells. The waters of these wells had suddenly become so hard as to be unfit for use, and the wells were abandoned. The amounts of chlorides in a number of samples of water collected from these wells varied a great deal, the highest being 900 p.p.m.

In conclusion, it might be well to consider that while the cases enumerated have referred to private water supplies, under similar conditions public ground water supplies might become contaminated. Experienced water department officials and engineers can do a great public service by giving advice and counsel relative to the proper location and protection of private water supplies.

TABLE OF ANALYSES

	Date of Collection	APPEARANCE			ODOR	Residue on Evaporation		AMMONIA			Nitrogen as		Chlorides	Hardness	Alkalinity	Iron	Manganese	Oxygen Consumed	Bacteria Per c.c.			Coli-Aerogenes Group in			
									Albuminoid										4 Days	24 Hrs. 37° C.		.1	1	10 cc.	
		Turbidity	Sediment	Color	Odor	Total	Loss on Ignition	Free	Total	Dissolved	Nitrates	Nitrites							20° C.	Total	Red	cc.	cc.	No. Pos.	No. Neg.
Spring "A"	—	none	none	0	none	169.0	—	.000	.004	—	.020	.000	1.3	129	—	.05	—	—	18	1	0	0	0	2	3
Spring "B"	1931	none	very slight	0	none	335.0	—	.000	.076	—	15.000	.005	19.9	146	—	.12	—	—	150	12	1	0	0	0	5
	1935	very slight	very slight	2	none	311	—	.014	.046	—	15.550	.006	10.6	126	—	.00	—	—	130	12	2	0	0	3	2
Dug Well "A"	—	decided (iron)	very considerable	12	distinct unpleasant	213	—	.062	.066	—	8.800	.120	14.0	57	—	12.0	—	Oil .004%	650	3	0	0	0	0	5
Dug Well "B"	—	none	none	4	none	161.0	—	.018	.050	—	.800	.020	5.9	30	—	.08	—	—	1050	170	30	+	+	5	0
Dug Well "C"	—	distinct (iron)	considerable	7	decided offensive	292	—	22.4	.560	—	.60	.005	70	150	188	13.0	—	—	—	2	0	0	0	4	1
Tubular Well "A"	—	very slight	very slight	0	very faint unpleasant	.2360	—	.002	.004	—	.30	.030	1050	169	—	.12	—	—	710	45	20	0	+	5	0
Tubular Well "B"	—	none	none	3	none	127	—	.000	.006	—	2.40	.000	20.8	40	—	.05	—	—	12	8	0	0	0	0	5
Tubular Well "C"	—	slight (clay)	considerable	18	none	143.0	—	.004	.001	—	1.500	.020	14.5	54	—	.50	—	—	2300	3	1	0	0	0	5
Pond in vicinity of Tubular Well "C"	—	slight	slight	44	distinct unpleasant	75.0	32.0	.040	.420	.236	.020	.000	10.8	26	—	.85	—	—	210	15	3	0	+	5	0
Tubular Well "D"	—	none	very slight	0	distinct musty	86.0	—	.096	.048	—	.020	.000	5.4	46	—	.05	—	—	3800	2	0	0	0	0	5
Tubular Well "E"	—	distinct	slight	42	decided offensive	314.0	—	.016	.644	—	.200	.000	14.0	175	160	2.80	8.00	15.6	8400	10	4	+	+	5	0
Tubular Well "F"	—	very slight	slight	0	very faint unpleasant	164.0	—	.022	.056	—	.580	.007	36.6	61	—	.62	—	—	1500	3	1	0	+	5	0

POLLUTION OF AN INDUSTRIAL GROUND WATER SUPPLY BY ORGANIC WASTE PRODUCTS

BY GORDON M. FAIR*

[*Read March 16, 1939*]

The control of the catchment area of surface water supplies to safeguard the quality of the water produced is generally accepted practice. It is the purpose of this brief note to show that the intake areas of ground water works, too, may need attention if the quality of the water is to be preserved.

The ground water supply in question was developed by a manufacturing establishment requiring large quantities of water for cooling purposes. The municipal water supply was used during the winter, but draft was shifted to a series of wells in the summer to secure the benefit of cooler water. The wells varied in depth from 125 to 250 ft. penetrating a 100-ft. stratum of dark sand and gravel overlying fine white sand and gravel. The area in the immediate vicinity of the wells, therefore, was extremely permeable.

The well field gave satisfactory service for a number of years. The water was soft and low in iron. A mineral analysis showed about 70 p.p.m. of total solids with a loss on ignition of about 15%, 22 p.p.m. of hardness and an iron content of less than 0.2 p.p.m.

During the fourth year of operation, troubles appeared in the water distribution system. Pipes became clogged by rustlike, but slimy, deposits, and the efficiency of coolers and condensers was greatly reduced. An examination of the supply by the author showed the presence in the water drawn from the wells of 6 p.p.m. of iron, 140 p.p.m. of hardness, and 240 p.p.m. of total solids, with a loss on ignition of about 40%. The free CO_2 content was 110 p.p.m. and the dissolved-oxygen saturation value equalled 45%. Since an air-lift was employed for pumping, it is probable that the water entering the wells was actually devoid of oxygen and that the concentration of carbon dioxide was higher than the measured value.

Filtration of the water and microscopic examination showed the presence of but a small amount of amorphous matter. A black growth, about ¼ in. in thickness, covering the pipes of an ammonia condenser, however, proved to be a mass of iron bacteria—*Crenothrix*—together with amorphous matter and a few protozoa.

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How could an originally satisfactory supply deteriorate to such an extent? The answer was found in a survey of the catchment area in the immediate vicinity of the well field. Here upon low-lying land was spread a mass of organic waste matter, largely spent wort, produced by the industry. The wastes were decomposing slowly and polluting the soil. That the products of decomposition actually penetrated to the wells in the water leaching into the ground was evidenced by the odor of the well water which was of exactly the same character as that of the organic waste products in the dump.

The analysis of the water shows that the conditions created unwittingly by the dumping of the waste products of the industry in the vicinity of the well field were ideal for the solution of iron and for the support of iron bacteria. The heavy growth of these filamentous organisms, which precipitate iron upon the gelatinous sheath that surrounds them, was responsible for the troubles experienced with piping, coolers and condensers, rather than the iron content of the water itself, or corrosion due to the very acid reaction of the water and the large amounts of carbon dioxide in solution.

As for surface water, the life history of ground water, too, is reflected in its quality. Under favorable conditions, the modifying influence of filtration may be such as to deliver a repentant but acceptable water even from an intake area that contains moderate amounts of organic matter. Where pollution is close to the point of draft and gross in amount, as in the case presented in this note, watershed sanitation must be instituted to preserve the quality of ground water.

NON-ORGANIC POLLUTION OF WELL SUPPLIES

BY E. SHERMAN CHASE*

[*Received May 24, 1939*]

During the past few years three instances of pollution of ground water by illuminating gas or its products, have been investigated under the writer's direction.

The first case occurred at Ipswich, where the water supply of a drug store developed a strong odor of illuminating gas. This water supply was derived from a dug well 20 ft. deep with about 6 ft. of water. The well was located across a narrow roadway at a distance of 40 ft. from the store. A small pumping and pressure tank outfit was located in the cellar of the store. The suction pipe, laid 4 to 5 ft. below the surface extended from the pump under the roadway to the well. This pipe was of wrought iron and had been laid many years before the occurrence of the gas pollution. A gas main, laid at a depth of about 2 ft., was located in the roadway and crossed the line of the suction pipe near the store.

When the gas company was notified of the condition of the water it investigated the gas main, discovered a leak near the store, and promptly repaired the main. The gassy odor, however, persisted in the water.

An investigation of the water as it was in the well showed no trace of gas. In view of the age of the suction pipe from the pump it seemed probable that a leak existed therein and that air or ground water impregnated with gas was being drawn into the suction pipe from the soil in the vicinity of the gas main. The suction pipe was dug up, a leak discovered, new pipe laid and the trouble disappeared.

A second case of gas pollution of a shallow well occurred a year ago at a summer cottage at Seabrook Beach, New Hampshire. About the first of October 1937, a house-service gas pipe was accidentally broken and some 100,000 cu. ft. of gas escaped into the sand during a period of less than 24 hours. The cottage to which the gas-service pipe was connected was supplied by a driven well less than 20 ft. deep and approximately 40 ft. easterly from the point at which the gas leak occurred. The soil consisted wholly of beach sand, and the ground water table was a few feet only below the surface. When the

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well was driven, fresh water could be obtained to a limited depth, after which brackish water was encountered. Due to the fact that the winter season intervened between the gas break and the opening of the cottage in the spring, the gas pollution of the well was not discovered until about six months after the break occurred. After this discovery, the gassy odor in the water persisted. A new well was put down approximately 40 ft. northeasterly from the location of the leak, and satisfactory water obtained therefrom all last summer. The pipe and well point of the old pump were pulled up and a distinct gassy odor was observed on them. The general direction of ground water flow would probably be from the leak towards the old well but away from the new well.

The most interesting and the most puzzling of the three cases of gas pollution took place and, so far as the writer knows, is continuing at the present time, in a tubular well just outside the city of Putnam, Connecticut. This pollution resulted in court action brought by the owner of the well against the city, on the grounds that the city dump a few hundred feet distant, was the source of the pollution, for reasons which will appear later. The judge of the Superior Court, who heard the case, found for the City, but an appeal was taken and is pending as this paper is written.

The well involved is a drilled well about 85 ft. deep located under the tenant house of the plaintiff. It was put down about 30 years ago and is said to penetrate sand and gravel only, without reaching bed rock. The casing is 6 in. in diameter and terminates about 4 ft. below the cellar floor in a well sump about 3 ft. in diameter and 4 ft. deep. The water is pumped by means of a deep well pump, electrically driven, to a steel pressure tank. The barrel of the pump is said to be located at a depth of about 65 ft.

Some time in 1934, it is alleged, the water from the well developed a decidedly unpleasant odor typical of illuminating gas. Late in November of that year a sample analyzed by the State Department of Health showed the presence of phenol, a coal tar derivative not normally present in unpolluted ground waters. Furthermore, the Health Department in reporting upon the analysis referred to the high nitrate nitrogen and chloride content. The gassy odor and the presence of phenol and high nitrates and chlorides persisted, and the water last summer continued to be decidedly objectionable for domestic use, due to the gas odor.

A high-pressure gas main laid in the highway to a depth of 4 or 5 ft. passes the well about 70 ft. distant. Naturally the most likely

source appeared to be a possible leak in this gas main or one of the nearby services leading therefrom. The gas company claimed that such a leak did not exist, and suggested that the cause of the pollution was gas main drip and iron oxide and shavings from the scrubber of the gas works, which had been deposited in 1930 and 1931 upon the city dump. This dump is located approximately 1,000 ft. northeasterly from the well and east of a railroad embankment separating the property of the plaintiff and the property of the city. The dump has been in operation since the spring of 1923, and is used for the disposal of rubbish, a variety of wastes and discarded materials, and some garbage.

The general slope of the land is from the east and northeast to the Quinebaug River, and from the dump toward the well in question. The topography, however, is so irregular that surface drainage from the dump is northerly to a small brook which enters the river about 1200 ft. north of the well. The soil is glacial sand and gravel. The nearest outcrop of ledge appears to be at the top of a cross road some 1500 ft. distant from the well. Test wells back and east of the tenant house indicated ledge at a depth of about 70 to 75 ft. below ground level. Although there are low hills of sand and gravel back of the railroad embankment intervening between the dump and the well, there appears to be no ledge at a sufficiently high elevation to cut off such ground water movement as may occur between the dump and the well.

There is evidence, however, that the valley in which the well is located consists of a trough in the bed rock filled in with glacial deposit. This trough appears to slope from the north to the south, or from the city to the location of the well but with shallow cover at the city and deep cover at the well.

In view of the possibility of the high pressure gas main being the source of the pollution, tests were first made to determine whether there were any substantial gas leaks that might be permeating the soil in the vicinity of the well. These tests were made by means of a J-W combustible gas indicator, standard equipment, which permits the detecting of inflammable gases. Many exploratory holes 2 to 3 ft. deep were driven on the easterly side of the highway along the line of the high-pressure gas main. These holes were placed about 6 ft. apart. Other holes were driven near the gas service pipe to the tenant house and at several points around the house and near the well. Tests were made of the air in these exploratory holes and in every instance no evidence of combustible gas was obtained. While the instrument used

does not permit accurate quantitative results, it is sensitive to the presence of about 1% of gas.

Following these tests, additional tests were made at the city dump by driving test holes into the old fill over a small area above the approximate location at which the wastes from the gas company were dumped in 1930 and 1931. The presence of a combustible gas was clearly indicated in these holes by the testing instruments, but the odor of the gas drawn from the test holes was not that of illuminating gas nor was it similar to the gassy odor in the well. The gas found was probably a mixture of various gases generated by the decomposition of organic substances in the dump. A test hole just beyond but adjacent to the westerly limit of the dump, in the direction of the well, gave negative results.

In August, 1937, an 8-hour pumping test was run upon the well. The rate of pumping was measured at 15-minute intervals. Samples for partial chemical analyses were taken every hour, and samples for bacterial examination at the start, middle and end of the test. The total quantity of water pumped during the 8 hours was equivalent to an average discharge of 12 g.p.m.

Analyses of the samples collected during the test showed very little change in the quality of the water between the beginning and end of the test. The water continued to have a decided gassy odor during the whole 8 hours of pumping, with no apparent diminution in intensity. Bacterial examinations gave no evidence of active pollution.

Beginning in July and ending in November, 1937, samples were collected at weekly intervals for analysis. In general, the analyses indicated a water of reasonably uniform characteristics. The nitrate and chloride contents were above normal for unpolluted ground waters in this vicinity and the gassy odor continued with practically undiminished intensity, throughout the whole period of sampling and into the spring of 1938. Phenol also continued to be present. The results of the analyses are given in Tables 1, 2 and 3.

The presence of phenol in the well water indicates pollution by some substance of coal tar origin, consequently the results of the tests for this material are of some significance. A study of the results shows that in general the amounts of phenol found in the water after the middle of September were less than prior thereto. It is interesting to note that the samples collected at the time of the pumping test in August showed lower phenol content than had occurred previously or immediately thereafter. This may be due to the fact that just prior to the pumping test there had been a heavy rainfall which

TABLE 1—NITROGENS IN WELL WATER FROM TUBULAR WELL, JULY TO OCTOBER, 1937

Results are stated in parts per million.

DATE	ALBUMINOID NITROGEN	AMMONIA NITROGEN	NITRITE NITROGEN	NITRATE NITROGEN
July 27	0.060	0.084	0.035	—
Aug. 3	0.057	0.040	0.072	3.80
Aug. 10	0.076	0.098	—	2.80
Aug. 18	0.016	0.060	0.100	2.4
Aug. 24	0.028	0.030	0.060	2.4
Sept. 1	0.030	0.030	0.110	1.6
Sept. 8	0.026	0.038	0.120	1.6
Sept. 15*	0.152	0.082	0.330	1.8
Sept. 23	0.016	0.080	0.330	2.4
Sept. 28	0.012	0.024	0.070	2.8
Oct. 6	0.020	0.024	0.096	2.8
Oct. 14	0.024	0.032	0.100	2.4
Oct. 21	0.024	0.028	0.120	2.4
Oct. 26	0.024	0.038	0.120	2.4
Nov. 3	0.043	0.081	0.065	3.6

Samples on Aug. 24 and on and after Sept. 15 taken from pump discharge, other samples from distribution system.

*Just before this sample was taken, water from a broken pipe leaked into the well around the top of the casing.

TABLE 2.—SOLIDS, CARBON DIOXIDE, ALKALINITY AND HARDNESS IN WELL WATER FROM TUBULAR WELL, JULY TO OCTOBER, 1937

Results are stated in parts per million.

DATE	RESIDUE ON EVAPORATION	LOSS ON IGNITION	FREE CARBON DIOXIDE	ALKALINITY	HARDNESS
July 27	201	63	12.0	57.0	110
Aug. 3	197	97	11.0	55.0	116
Aug. 10	207	80	10.5	47.0	127
Aug. 18	202	70	11.0	50.0	108
Aug. 23-24	216	56	—	52.0	—
Sept. 1	211	67	12.0	46.0	111
Sept. 8	223	64	10.5	55.0	116
Sept. 15*	227	70	9.0	57.0	120
Sept. 23	218	45	9.0	56.0	128
Sept. 28	223	68	10.0	53.0	124
Oct. 6	231	75	12.0	51.0	124
Oct. 14	222	64	10.5	53.0	134
Oct. 21	210	61	14.0	49.0	120
Oct. 26	192	56	15.0	53.0	138
Nov. 3	264	56	13.5	54.0	144

Samples on Aug. 24 and on and after Sept. 15 taken from pump discharge, other samples from distribution system.

*Just before this sample was taken, water from a broken pipe leaked into the well around the top of the casing.

TABLE 3.—HYDROGEN-ION CONCENTRATION, CHLORIDES, IRON AND PHENOL IN WELL WATER FROM TUBULAR WELL, JULY TO OCTOBER, 1937
Results, except pH, are stated in parts per million.

DATE	pH	CHLORIDES AS CL	IRON F_e	PHENOL
July 27	7.1	24.2	0.5	0.027
Aug. 3	6.9	23.0	0.5	0.040
Aug. 10	6.8	27.5	—	0.040
Aug. 18	6.9	24.5	0.4	0.050
Aug. 24	6.9	23.5	0.08	0.002
Sept. 1	6.9	26.5	0.4	0.040
Sept. 8	6.9	27.0	0.6	0.040
Sept. 15*	6.9	27.0	0.9	0.050
Sept. 23	6.9	28.0	0.4	0.030
Sept. 28	6.9	28.0	0.1	0.040
Oct. 6	6.9	28.0	0.1	0.003
Oct. 14	6.9	28.5	0.4	0.010
Oct. 21	6.9	27.2	0.2	0.003
Oct. 26	7.0	20.0	0.1	0.000
Nov. 3	6.7	30.5	0.1	0.003

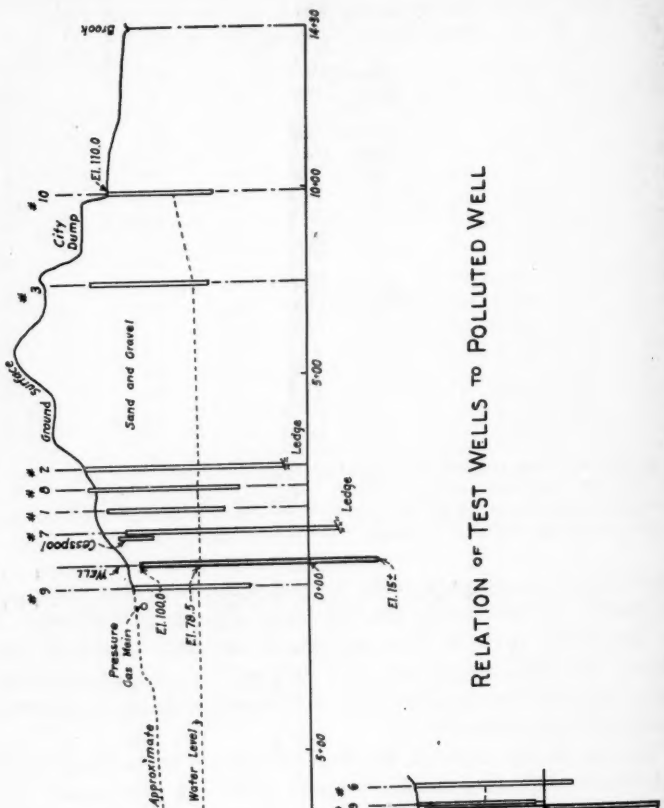
Samples on Aug. 24 and on and after Sept. 15 taken from pump discharge, other samples from distribution system.

*Just before this sample was taken, water from a broken pipe leaked into the well around the top of the casing.

brought about the dilution of the ground water with rain water which had rapidly percolated into the soil in the vicinity of the well. It is also interesting to note that the phenol content decreased during October, the last sample collected during that month showing no phenol, although the sample taken on November 3, again showed the presence of this substance.

In view of the fact that the well throughout the summer of 1937 yielded water having a decidedly gassy odor, it was necessary to put down test wells to establish the extent to which this gassy odor was present in the ground water. Furthermore, other than the characteristic odor of illuminating gas there were no data to show the presence of leaks in the nearby gas pipes. Consequently, the test wells were needed to determine whether or not there was any evidence indicating that the city dump was bringing about the pollution of the well or of the general ground water in the vicinity.

In all, ten test wells were put down. Four of the wells were located between the well and the dump; one was located near the cesspool of the tenant house, three were located along the highway near the gas main in front of the house; one was located near the highway about 400 ft. north of the tenant house; and one well was



RELATION OF TEST WELLS TO POLLUTED WELL

put down on the east side of the dump at a spot indicated by the plaintiff as that nearest which the gas wastes had been placed in 1930 and 1931. (See Figure)

In general, the depth of the wells was sufficient to penetrate the ground water table to a limited distance only inasmuch as it is well known that pollution entering the ground water from the surface tends to remain on top of the ground water table. Two wells, however, were driven sufficiently deep to locate ledge but none was driven quite as deep as the well of the tenant house. The ground water table was almost level but had a slight slope from the dump towards the well. Obviously the rate of ground water movement was very slow.

Of all the test wells put down, only one located about 155 ft. northeasterly from the well, showed the presence of the gassy odor. Two wells close to the dump failed to yield water possessing any odor of gas. One well located close to the railroad track, with creosoted ties and oil treated ballast, showed some phenol, but none of the other test wells gave similar results. Table 4 summarizes the analyses of samples from the test wells.

In connection with the test well from which the sample showed the presence of some gassy odor, it should be pointed out that in the driving of this well, water from the tenant house well was used to wash out the sand. This fact results in some doubt as to whether the samples taken from this well were or were not affected to some extent by the character of the wash water.

The fact that none of the other test wells showed the presence of the gas even when located close to and in the city dump, indicates that the gas pollution was not coming from the dump. Unfortunately, the exact source of this pollution was not discovered. It seems to the writer that the gas pollution was probably due to gas, gas main drip or liquid wastes from the manufacture of gas entering the ground water table more or less continually at some point in the valley where the ground water table is close to the bed rock and also where the direction of ground water flow would be towards the well. The investigation was not continued to the extent of demonstrating the correctness of this theory as the purpose of this study was to determine whether or not the city dump was responsible.

It seems to the writer that the tests showed conclusively that the dump was not the source of the pollution. If the pollution were coming from the surface, test wells penetrating the ground water table would be sure to intercept water containing the pollution, whereas if the pollution was being introduced just above the bed rock it would

TABLE 4.—SUMMARY OF ANALYSES OF SAMPLES FROM TEST WELLS
Results, except temperature, are stated in parts per million.

	TEST WELLS											
	T	1	2	3	4	5	6	7*	8	9	10	C
Temperature—°C.		9.5	13.0	13.6	9.0	9.5	11.0	10.7	11.0	10.3	10.3	
Nitrite Nitrogen	0.109	0.042	0.005	0.020	0.000	0.001	0.007	0.004	0.013	0.039	0.006	0.000
Nitrate Nitrogen	2.5	2.1	0.15	0.13	0.03	1.2	0.08	4.2	0.90	1.2	0.04	0.06
Carbon Dioxide	15.4	22.2	5.3	3.0	8.3	12.0	4.0	24.5	4.0	15.8	1.9	4.0
Alkalinity	42.0	22.6	33.7	35.3	19.0	20.5	30.0	28.3	20.0	13.5	43.0	26.0
Hardness	154.0	68.0	38.0	52.0	29.0	43.0	33.0	103.0	38.0	63.0	49.0	27.0
Chlorides	26.1	19.4	6.1	12.8	3.5	9.0	7.8	34.0	10.3	13.5	3.0	4.5
Phenol	0.004	0.000	0.000	0.020	0.000	0.000	0.000	0.000	0.000	0.000	0.000	—

T—Tubular well, October 6 to 26 inclusive.
C—City water.
*61 ft. depth.

tend to travel along the plane of the rock and as the rock slope is downwards towards the bottom of the well such pollution would reach the deeper ground waters without affecting the supernatant waters.

The analyses of samples from test well No. 7, located close to the cesspool of the tenant house, show quite definitely that this cesspool was the source of the high chlorides and nitrates in the tenant house well. No phenol nor gassy odor, however, were found in the samples from well No. 7 nor in the cesspool liquor thus showing an independent source for the gas pollution.

RAPID SAND FILTRATION PLANT FOR WILLIMANTIC, CONNECTICUT

BY ROLAND F. KITTREDGE*

[*Read April 27, 1939*]

The city of Willimantic, a community of 12,500 people is supplied with water by the Willimantic Water Department, a publicly owned surface supply that was inaugurated in 1885. Prior to this time water was procured from private wells. Water is pumped into the distribution system, any excess over consumption entering a balancing reservoir which furnishes water by gravity at off-pumping periods.

Source of Supply: A concrete dam across the Natchaug River just below the confluence of that stream and the Fenton River, impounding something over 120 m.g. creates with the stream flow a source sufficient, not only for water supply but also during the major portion of the year for hydraulic power for the high-lift pumps.

The 162 sq. miles of drainage area above the dam, including much farm land and swampy sections produce a water, the physical and chemical characteristics of which in general are unsatisfactory. The organic content is unusually high, causing a high color with abnormal tastes and odors. The water is soft with an average soap hardness of 19 p.p.m. and a pH value ranging below 7.0, so that a fairly corrosive water results. To correct and overcome these conditions, the present filtration plant was designed and constructed. On April 20, 1935, work was started as a W.P.A. project, under Mayor James H. Hurley, and a water committee composed of Alderman Harry J. Kaufman, Chairman, and Aldermen Aimie J. Boucher and M. E. Lincoln. The plant was completed and put into operation in June 1937 during the administration of Mayor Pierre J. Larammie and a water committee consisting of Alderman Aimie J. Boucher, Chairman, Alderman Joseph M. Berard, and Frank Cabit. John F. Collins, City Engineer, supervised the construction of the plant.

Filter Plant

Pumping. From the raceway leading to our pumping station a 14-in. suction line, over which there is a normal 10-ft. head, leads to the low-lift pumps. The water first passes through a screen consist-

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VIEW OF FILTER PLANT FROM ENTRANCE

ing of two thicknesses of Irish linen cloth. The cloth is changed monthly, or more often if necessary.

Two low-lift pumps—one a centrifugal pump rated at 1100 g.p.m. with a total dynamic head of 46 ft. that is driven by a 15-h.p. electric motor operating on 220 volts and running at 1750 r.p.m., the other a turbine pump rated at 950 g.p.m. with a total dynamic head of 42 ft.—are located in a vault adjacent to the pumping station. The turbine unit when operating is driven by water taken from the discharge line of the high-lift pumps and discharged to the suction of the same pumps, thereby using filtered water. The discharge pipes from the low-lift pumps are installed with a check valve and gate valve near the pump outlet.

On the wall near these pumps is a panel board with 5 indicating dials, showing the gallons per minute delivered when operating with the water turbine, the turbine inlet and outlet pressures, the low-lift discharge in feet and low-lift suction in feet of vacuum or pressure. A flow-indicating and recording meter, operating from a Venturi tube in the raw-water line, is located in this room, and the indicating is also transmitted to a dial on the panel board in the filter building.

In an emergency it is possible to by-pass the filter plant. The supply would, in this event, be chlorinated at the pumping station. The interconnection is separated by two valves and a drip. It is necessary normally to lift the water about 18 ft. to the purification building.

Aerator. The first process in the purification at the filtration plant is that of aeration. All the raw water enters the aerator tank which is situated about 8 ft. above the normal water level of the plant. The outlet is through an annular head from which air stacks rise to a point above the surrounding water level, and down past the lower ends of small proportionately spaced tubes in multiple arrangement, extending from the head down into the annular throat. A gravity flow is created by a difference between the water level in the tank and the level in the retention basin. At the point where the downward flow passes the lower ends of the tubes air is aspirated into and mixed with the water to form a seething mass of water and air bubbles. The travel of this mixture is continued downward through a U-shaped retention pipe, wherein the mixture is entrained for a definite period, establishing intimate contact between air and water before discharging over a conical plate above the surface of the water. Turbulent surface travel over herringbone corrugations effects a quick release of entrained air bubbles, with consequent reduction of objectionable odors, the expulsion of dissolved gases and light volatile oils, and the removal of iron.

Coagulant, and alkali when necessary, are added in the retention pipe of the aerator, and a vigorous mix is thus obtained. The aerator basin provides about 16 min. detention. The tank which is provided with an over flow may be by-passed and the basin, conditioning tank and coagulated-water channel may be drained from a sluice gate in the aerator unit.

Mixing Basin. From the aeration basin the water flows through a 24-inch square opening at the base of the separating wall into the conditioning tank in which an electrically driven paddle apparatus with four forward speeds, operates at rates from 1 to 4 r.p.m. We usually employ the 1 r.p.m. The agitator consists of three sets of arms on a central shaft, set to give an upward motion to the water at the center of the well. Carbon is fed to the water at the entrance of the conditioning tank, or may be fed to the settled water just prior to filtering. When heavy doses are necessary, split treatment is employed, otherwise the chemical goes to the settled-water conduit. Chlorine may be added at the opening in the separating wall when it

is desired to pre-chlorinate. The conditioning tank provides a detention period of 17 min., making a total of 33 min. that the water is retained in these two processes.

Four dry feeders are located in the chemical feed room situated directly over the conditioning tank. One feeder is adapted to the feeding of heavy free-flowing chemicals requiring no special agitation within the hopper. The feed spout has a curved orifice plate, adjustable for three positions of opening. Coagulant is fed from this machine. Three other feeders are provided with special agitation within the hopper. The feed spout is equipped with a feed roll assembly also adjustable for three positions of openings and operated by means of a feed-roll lever and actuating link. Each of the four feeders is provided with a graduated adjusting scale, which may be set by the operator to furnish the chemical at a definite predetermined rate. The chemical mixing is enhanced by the presence of high-pressure ejectors at vital points in each of the solution feed lines.

Settling Basins. From the top of the conditioning tank the flocculating water passes through a conduit having a cross-section of 2 ft. by 2½ ft., at a velocity of less than ½ ft. per second, to the end of the settling basins away from the filter building. It then continues to an influent conduit consisting of a concrete channel 3 ft. wide and 2½ ft. in water depth, with eight 6-in. holes discharging downward into the basin behind an under-baffle, and each basin is also fitted with an over-baffle and another under-baffle. Two basins 57 long by 25.5 wide by 13 ft. deep used in parallel give a detention period of practically 4½ hours. The basin floor is sloped, and two drains leading from each basin to a center manhole aid in their cleaning. The settling basins are cleaned every two months from April to November.

Filters. The effluent conduit carries the settled water from the top of the basins to a manhole directly in front of the filter building, where the water flows downward into a header from which three 12-in. cast-iron pipes take it to the three central gutters, thence to the filters. The hydraulically operated influent valves are located in the ends of the cast-iron pipes. The gutter system of wash-water troughs helps to distribute the water equally without causing currents.

The filtering area is made up of three units each 18 by 10½ ft. having an area of 189 sq. ft., the total plant area being 567 sq. ft. The filtration rate is about 125 m.g.d. per acre for the design capacity of 540,000 g.p.d. per unit, although the normal rate is about 115 m.g.d. per acre or 1.8 g.p.m. per sq. ft. The underdrainage system is composed of a series of 6-in., half-round cast-iron pipes spaced 12 in.

on centers with 1-in. holes drilled 6 in. on centers and raised from the floor by ½ in. by means of special spacers. These drains are connected to the manifold conduit under the central gutter. On the underdrainage system rest 18 in. of graded gravel ranging in seven sizes from 2½ in. at the bottom to 1/16 in. at the top. This supports a 30-in. sand bed. The sand has an effective sand size of between 0.4 and 0.5 m.m. and a uniformity coefficient of less than 1.6.

In each of the three filter units there are three wash-water troughs with a maximum lateral draw of 2½ ft. A wash-water rate of 19 g.p.m. per sq. ft. or a 30-in. rise is employed and gives approximately 40% of sand expansion, except during the winter months when a wash-rate of 15 g.p.m. per sq. ft. is used. The freeboard is 2½ ft. from the top of the sand to the top of the troughs. The wash-water discharges to the central gutter and thence through a 14-in. hydraulically controlled drain valve. It is carried to the river below the dam.

Wash-water Tank. The wash-water is taken from a 40,000-gal. elevated tank located in the rear of the filter plant. This tank is filled through a 3-in. connection taken from the main on the discharge side of the heavy-duty pumps, the level of which is controlled by an altitude valve set in the supply line with ½-in. diaphragm-control pipe connection made to the tank riser, maintaining the desired water level in the tank.

Filtered-water Basin. The filtered water basin is under the filter house and is 59 ft. by 30 ft. wide by 10 ft. deep and will hold about 135,000 gal. At a rate of 1.5 m.g.d., the detention period is about two hours. The basin is divided into two compartments. The filtered water enters the smaller one and has to pass through a 12-in. pipe to the larger one. Chlorine, ammonia and lime are added in this pipe. The chlorine is added by means of a manually-controlled solution-feed vacuum chlorinator. Ammonia is added prior to the chlorine. We have noted from actual practice that several advantages are obtained by using chloramine. Higher residuals may be carried without danger of imparting a chlorinous taste to the water. We maintain a residual of about 0.4 p.p.m. at the outlet of the clear-water basin and have thus far received no serious complaints. This treatment prevents the formation of combination tastes of chlorine with organic matter, and the residual may be retained for a long period in the distribution system, thereby providing safety against contamination which might enter there. Tests have been run from time to time practically all over the city and, with the exception of a few dead-end

sections, a persistent residual may be noted. We have found that a 6 to 1 ratio of chlorine to ammonia appears to give the best results. The ammonia is fed to the water with a manually controlled direct-feed ammoniator.

Lime as an anti-corrosive is applied in suspension also at this stage to keep the pH value of the finished water at about 8.5. By so doing we hope to offset unfavorable conditions in dead ends.

Measuring Equipment. Various gauges, indicators, scales and appurtenances aid in the operation of the plant. The ammonia and chlorine cylinders are set on scales, and daily readings are made. A set of scales is also available in the chemical feed room where time weighings are made periodically of each chemical being fed to check the operation of the chemical dry feeders. A panel board in the operating room has three dials, one 24-in. dial showing the rate of flow of wash-water through an orifice meter. Mounted next to this is a totalizing meter register from which the total amount of wash-water used for each washing is read. The third meter on the board shows the rate of flow from the low-lift pumps. A filtered-water stage, float-indicator is set up in the operating room. There is a comparator unit with running water showing the water in three stages —raw, settled, and finished—for inspection by visitors.

Valves. All large valves used in operating the filters are hydraulically operated from control tables set in front of each of the filter units. Tell-tale arrows wired from the piston rods reveal the working of the valves. On these operating tables are indicating and recording dials showing the rate of flow and loss of head of the filter, at all times. The rate of flow on the effluent line in the pipe gallery is controlled by a pilot-valve unit, directly actuated by a diaphragm which is pressure-connected to the inlet and throat of a Venturi controller tube, a pendulum unit interprets the record from change in pressure to terms of gallons per day on the rate of flow dial. The loss of head, also measured by a diaphragm arrangement set up in the pipe gallery, and the pressure difference between the water surface on the filter and that in the filtered water conduit are recorded, and a pendulum unit transfers the pressure change to terms of feet on the loss of head dial.

Chemicals. Chemicals are received by truck and carried to the storage room on the second floor where it is possible to store a split carload. An Electro-lift mono-rail hoist aids in the handling of the chemicals. Hoppers are positioned over the dry feed machines so that the chemicals are added directly from the store room.

Laboratory. On the second floor of the plant is the laboratory where physical and chemical tests, essential to the efficient and economical operation of the plant are carried out. Tests are run daily on the raw and filtered water, or more often when the raw water varies. These daily examinations are for temperature, turbidity, color, alkalinity, pH value, free CO_2, soap hardness, iron, chlorides and odor. Frequent residual chlorine tests are made on the effluent. We are now inaugurating a bacteriological setup and will run daily *B. coli* presumptive and confirmed tests, together with total plate counts at 37 degrees Centigrade on the raw, settled and filtered water. These will be in addition to the bacteriological tests now made by the State Department of Health. Other tests made from time to time are for free alum, the marble test for corrosion, jar tests, threshold odor and other tests that might suggest themselves through a possible improvement in process or savings in material.

Operating Results

Water Quality. From the average color of 40 p.p.m., that at times reached 140 p.p.m. before the installation of the purification process, we now furnish water with an average color of about 2 p.p.m., while the average turbidity of 2 p.p.m. has been reduced to practically 0. The pH value of the water, formerly at an average of 6.5, is now sent to the consumer at around 8.5. The alkalinity has increased from an average of 11 p.p.m. to about 16 p.p.m. and the hardness from 19 p.p.m. to about 30 p.p.m., and the free CO_2 has been eliminated. Although iron was never found to be present to a greater extent than 0.1 p.p.m. before or after treatment, it is evident that there is incidental reduction from the noticeable presence of iron oxide in the aerator unit.

Coagulation. We have concluded after many tests that the largest and fastest settling floc is formed by maintaining a pH value in the mixing basin of 6.2 in the warmer weather, with water above 50° F. However below this temperature, by keeping a pH of about 5.9, we get the best results. This concentration can be approximated by feeding 1¼ grains per gallon of alum in the warmer weather while 0.7 grains per gallon is the lowest amount we have been able to feed in the cold weather. The alum is supplemented by the addition of soda ash after a heavy storm when the alkalinity is likely to drop, or at other times when the alkalinity of the influent is low. The average alkalinity of the raw water is about 10 p.p.m.

To lower the amount of alum used, we attempted to add turbidity

by using sodium silicate and Fullers earth, but poor floculation resulted. Attempts to use iron as a coagulant proved unsatisfactory.

Odor Control. During certain seasons, we are troubled with algal growths and the attendant foul odor in the raw water. High river flows and relatively small storage make the use of copper sulphate uneconomical. It is possible, however to control odor troubles by the use of activated carbon. We are normally able to supply an effluent with a hot threshold odor of about 3, by using an average dosage of 0.15 grains per gallon. During periods of increased algal growths it is necessary to feed as much as 1.0 grain per gallon, or more, to approach this desired figure.

Care of Filters. Much attention is given to the care of the filter beds, realizing the importance they play in the part of furnishing a safe, clear, palatable water. A practice is made of regular sand inspection, and although we have been fortunate in avoiding the formation of mud balls, using the Baylis method, we have on several occasions noted ridges on the sand surface along the walls. We are able to eliminate this by using a 7-ft. length of ¾-in. pipe with a hose connection on one end and a cap with three 1/16-in. holes drilled in the side on the other end, which applies a high pressure stream in a horizontal direction to the affected area.

Records. Both as a matter of economy and from a standpoint of efficiency, daily plant records are kept showing the total water treated, each chemical used in terms of pounds per day, and grains per gallon or in the cases of chlorine and ammonia, parts per million, the amount of water sterilized, the average cost per day and cost per million gallons, the area of filter surface used, the number of units out of service if any and the reason thereof, together with an account of the units washed, amount of wash-water used, length of wash, hours run between washes and the percentage of wash-water used. Supplementing these data are the results of our daily physical and chemical tests both on raw and finished water. These records are kept on file at the plant, and copies are furnished to the State Department of Health, the Superintendent of the Willimantic Water Department and the City Engineer. During our first year of operation Mr. James A. Newlands of Hartford acted in a consulting capacity.

Distribution. The effluent from the clear well flows through a 12-in. pipe by gravity to the high-pressure pumps. A 4-in. connection in this line serves to drain the clear-water basin. The pumping station, a cut stone structure on the river bank some 200 ft. to the rear of the filtration plant, houses the heavy duty pumps. The main pumping

units are hydraulically driven. A Rodney Hunt water wheel drives a duplex reciprocating pump. An S. Morgan Smith hydraulic turbine drives a reciprocating pump with three single-action pistons. This unit may be driven by a 100-hp. induction motor through a V-belt drive and split coupling if the water level in the pond is low, which occurs regularly each summer. Both these pumps, are fitted with an air chamber, connected to an electrically driven compressor, and alternately take care of the entire pumping under normal conditions. The water is driven directly to the city main on which is set a Venturi tube that serves to record through a meter the rate of flow and totalizes the amount of water furnished by the pumps. A Barr duplex steam pump erected in 1895, although not in regular use, has been employed advantageously on several occasions. Two 100-hp. boilers generate steam for this pump.

As stand-by units we have four V-8 gasoline-driven emergency units. These units are of the single-stage high-pressure type centrifugal pumps, and the maximum pressure is between 300 and 400 lb. per sq. in. The maximum volume from draft is 500 g.p.m., the rated capacity, at 160 lb. per sq. in.

The distribution system is made up of approximately 55 miles of pipe on which are 2,100 services. An elevated storage for finished water is located on the highest point of the area served, and this reservoir has a capacity of between 5 and 6 m.g. Thus it is possible normally to maintain adequate and dependable service. Using a full reservoir connected to the system, it can be depended upon to furnish a large part of any peak demand by automatically feeding into the mains a part of the previously stored surplus. By the presence of this reservoir "floating on the line", we are able to insure fire protection and adequate domestic supply during a shut down of the pumping plant.

The purification plant has been in operation now for almost two years, and comments on the character of the water produced have been entirely favorable. Even some who doubted the wisdom of installing a filter plant are now praising the water produced. Thus Willimantic has been successful in serving its inhabitants with a greatly improved product.

CONTACTS WITH TOWN WATER AND FIRE DEPARTMENTS

BY PERCY C. CHARNOCK*

[*Read April 27, 1939*]

I presume the committee in selecting this subject wanted me to tell you something of my experiences as a fire-protection engineer in making surveys of water and fire departments. The investigating work which we have been doing in the interests of the Stock fire insurance companies has been underway for slightly over 30 years. My personal connection with the work now covers some 26 years.

I recall in the early days when we were sent to a city to start a survey we went with wonder and oftentimes misgivings as to how we would be received. I think on the whole the Mayors were cooperative, but if we had not been to that city before or the department heads were new on the job, we were not always given complete coöperation. In fact, our work was many times made difficult, I presume, for fear that our findings possibly would show incompetence and, therefore, react against the head of the department. In those days, it should be remembered, it was not nearly so common for the head of a water department or a fire chief to hold his job through successive administrations as is the case today. Consequently, we may assume it was somewhat natural for a man to endeavor to cover up his lack of knowledge of his department and to be reticent in welcoming us.

I think the fact that there are now less frequent changes in department heads is due in a great part to municipalities having accepted our recommendation to appoint department heads having proper qualifications, preferably experienced men, and that they hold office for an indefinite period, subject to removal only for cause.

I remember only one flat refusal on the part of a water department official to give me any information. It was in Maryland where it was said that the fire losses were heavy due to an insufficient water supply. I was somewhat inexperienced in dealing with "tough" propositions and, therefore, perplexed when the president of this water company told me I could not see one record, ask any questions or

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make any fire flow tests. He was kind enough to explain that a law suit was in process with the municipality over water rates and hydrant rental and that he was not willing to put any information into the hands of the municipality. When I told him that I was not there in the interests of the city and we would not give out any data, he still refused. Finding myself balked I told him that there was one thing he was going to do and that was to write a letter to my office explaining his refusal. He called in his stenographer and said: "Now you know the whole story. You dictate anything you want and I will sign it." I took the challenge, laid it on strong and he signed the letter.

The only time to my knowledge that we ever have recommended the removal of a department head was in one of the largest cities in Pennsylvania. The chief of the fire department was a political appointee who had no previous experience, and the morale of the department was very low. When it came to going into the records of discipline in the department, he flatly refused to allow us to see them. We made up our minds we were going to and sought advice from some of our friends. One of these friends was selected to return with us to the chief. The former told the chief that we needed the information to complete our study and that he would see that one of the strongest newspapers in the city would carry the story of his refusal if he persisted. The chief decided then we could see the records. This was at 4:30 P.M. and we went to work. At 5:00 P.M. he said the office was closed and we must return in the morning if it was necessary to go any further. In the morning his clerk informed us on the quiet that the chief had spent most of the previous evening removing many record cards from the file. We had obtained enough in the thirty minutes during the previous afternoon and in interviews with subordinate officers to prove that the discipline and therefore the morale were at very low ebb.

You possibly have heard me say something about providing for reliability of pumping equipment in pumping stations. I discussed this feature with the president of the water company at Roanoke, Virginia, a number of years ago, telling him that we analyze a water system on its ability to provide adequate fire supply both with one pump out of service and again with two out of service. He informed me that we fire-protection engineers were crazy and nitwits. He admitted that they frequently had one pump out of service but that to expect that two would be out at any one time was absolutely ridiculous. Some few days later, a Sunday morning, I found myself in the

vicinity of the pumping station. There was apparently considerable commotion at the station. I walked in and found my friend the president dressed for golf and apparently tearing his hair. In greeting me he said I was the damnedest Jonah he had ever run across. He had four pumps out of service and the standpipe was very nearly empty. There was one small pump discharging into the system. Had there been a serious fire at that time, the water company would not have been able to supply even a reasonable amount of water.

Something to be taken into account when designing a water system, if elevated storage is provided, is whether the draft on the system is enough to keep the water in storage from freezing. Several years ago, while making studies in a small town in Illinois, we found that a new elevated tank of the hemispherical-bottom type had been installed, and to our amazement we found the 4-ft. riser to this tank was frozen absolutely solid.

I have always been a very firm believer in keeping a very careful record of the operation of every valve in a water system and also of making periodical inspections of all valves to ascertain that they are in operating condition.

Within a few years one of our Eastern cities was troubled with a rather serious reduction in pressure in one end of the city. We were brought into the picture by various interests in this section and after conducting tests at numerous points, we suggested to the superintendent that in our opinion the cause of this reduction in supply was due to one or more valves being closed, and we suggested the approximate vicinity to look for the trouble. He seemed to scoff at this idea and attempted to lay it to deterioration in carrying capacity of one of the older pipe lines. We later had occasion to go to the mayor of this city and attempted to enlist his aid in having a suitable inspection of valves conducted. The mayor replied that he did not think he was particularly interested in this matter and that it was his opinion that the fire insurance interests were never satisfied. The superintendent of the water department had told him that nothing was wrong and the chief of the fire department had advised him that there was plenty of water available. I was not satisfied with this and told him I would like to have him go with me to a meeting of the water board and the superintendent so that we could thoroughly discuss the entire situation. This was finally agreed upon.

Prior to this conference, however, I had discussed with the water superintendent a change in method of pumping so that the discharge would enter the system directly and any excess would flow to the

reservoirs. At the time, the plan was to pump to the reservoirs and conduct water from there through another pipe line into the distribution system. He informed me that he had tried this and that it did not make any difference in the pressure so that my idea was absolutely wet.

At the meeting of the water board I attempted to impress upon them by figures the great reduction in the amount of water available in the lower end of the city and found that they had taken some recognition of it in that a study was being made to lay a very large main through the center of the city. In explaining my plan for immediately increasing the pressures through a change in the method of pumping the superintendent again informed me that I apparently did not know what I was talking about as he had tried the scheme and it did not increase the pressures. I told him that he certainly could not have done what I wanted to do because I was convinced and demonstrated by figures the savings in friction losses which could be made by the changed way of operation, and I offered to put my time against that of the water board in showing that it could be done. One of the water commissioners told the superintendent that he apparently was being challenged and, therefore, it would be a good thing for him to try and show me up if he could. Accordingly, arrangements were made and then we learned that the valves the superintendent had formerly operated were some which were necessary to complete the change, but that there was still one valve that had never been opened.

While we were going through the operation of the valves, I suggested to the superintendent that he probably would find it would not take quite so much coal to deliver the water into the system with this change in pumping since it would reduce the dynamic head at the pumping station by approximately 5 lb. per sq. in. He began to take a little interest in the plan at that suggestion, and true enough, when all the valves had been opened the head at the pumping station dropped immediately some 6 lb. per sq. in and the head at the other end of the system increased as we predicted. This temporarily helped the situation.

The city went ahead and laid the large main as planned, but in the meantime, on the advice of the city's consulting engineers, the method of pumping was changed to that which had been in use formerly. The completion of this large main naturally improved the supply to the lower end of the city immensely, but as time went on we found pressures were again receding. We again repeated our

request for an adequate inspection of all valves on the system. After much delay, but through pressure from the mayor, an inspection was started. One of the valves on this new 30-in. line was found to be very nearly closed; a number of valves along the line also were closed, and in all, as I remember, there were two 24-in., three 16-in and several 12-in. and smaller valves that were either wholly or partly closed. I feel quite certain that had this valve inspection been made at the time we first suggested it there would have been no need to lay this large main.

I might state here that finally the mayor, who had not been interested in our first story, reached the point where he hardly made any move in regard to the fire department or the water system without seeking our advice.

We occasionally have the opportunity to see fire departments in operation at fires. In one instance I found myself in charge of fighting a fire that occurred in the capital of the State of Louisiana, Baton Rouge. We had been engaged in an investigation of the fire-protection facilities and had completed our work with the exception of writing our report. There not being any trains on Saturday night, we were forced to remain until Monday. About 10:30 on Saturday night, the fire alarm rang and, looking out the window of the hotel room, I discovered that it was quite nearby on the main street. I instructed my assistant to pack up all of our data and belongings and check them with the clerk at the desk. Knowing something of the value of the fire protection, I anticipated that there was a possibility that the entire main street would be involved, for when we looked out the window the flames were shooting out the front of the building. On my arrival at the building I endeavored to get the men who were holding the first hose line to advance near enough to the fire so that the water would at least strike inside the windows, but I met with no success. Very quickly a number of other hose streams were brought into play on the front of the building and as each succeeding stream came in the other streams became weaker. I found that the fire department—a partly paid department and the balance volunteer—had laid all of the hose in the city and that not one of the streams was penetrating the fire.

I soon discovered the fire was getting into the buildings on either side of the point of origin which was, by the way, a 5 and 10 cents store. By this time I had urged the chief of the fire department to reduce the number of hose lines so as to have some effective streams that would get into the seat of the fire. He apparently took no stock

in my counsel because it was not done, and as conditions became worse I reached him again and told him that if he expected to save the town that was the only thing he could do. At that point the mayor stepped in and asked for my opinion of the situation. I referred him to the chief who repeated my suggestion and the mayor in turn informed the chief to do as I said. From that point on it was my fire. The chief was disgusted and took no pains in telling me so. However, I reduced the number of hose lines down to four (there was only 1,000 g.p.m. of water available in the water system), had the crowd cleaned out so that we could operate, and in what now seems a very short time the glare of the fire was dimmed and we soon had it under control. At 2 o'clock in the morning the chief came to me, apologized and said he had learned a lesson. He had always supposed the secret of combatting a large fire was to put as many streams of water onto it as possible. I told him that in all probability his theory was good but that he first must know how many streams of water his water system was good for. This chief now has a fully paid fire department, has gained considerable experience since that time and was very recently President of the International Association of Fire Chiefs.

About 1932, the Massachusetts Fire Chiefs Club asked me to speak at one of their monthly meetings on the subject of the fire department budget. I hesitated as we never had attempted to analyze such budgets and I felt I was not competent. However, on being pressed I agreed to talk on that subject and, in fact, my paper was given that title but there was little, if anything, in it in regard to the fire department budget. I did tell the fire chiefs, however, that the time had arrived when for their own salvation it was necessary for them to show the taxpayers that they had attempted to cut down the cost of running their fire departments. There had been, as you know, pay cuts and payless pay days and talk of further cuts in salaries. I suggested numerous ways in which I thought the cost might be reduced and gave a few rather homely examples. Among these was a possibility of saving on the electric light bill. Frequently I had been at fire stations at night when every light was burning unnecessarily; seen firemen polishing brass; one man was talking to another while he was pouring the polish from the can onto the waste and suddenly discovered the polish was dripping on the floor; he squeezed the waste out into the nearest cuspidor and, naturally, the chief would receive a request for another can of polish within a few days.

Well you can imagine the fire chiefs did not take very kindly to my suggestion of cutting down the costs. They raked me over the

coals pretty thoroughly when I had completed, telling me that I had considerable nerve to suggest that they reduce costs when my organization had been in the habit of recommending changes that would cost the cities large amounts of money. We had it back and forth for quite a while and when the meeting broke up many of them came to me and agreed I was absolutely right, that if they did not show the townspeople they had done everything to cut down the costs someone from the outside would step in and cut the costs and probably in some way that the head of the fire department would not appreciate.

Two days later the chief of one fire department telephoned me and said I was right in regard to electric lights. He had been out the previous evening and found every light in every fire station burning. A year later he told me his lighting bill was $480 less than during the previous year.

Now this brings me up to the situation we are faced with at the present time, with mounting tax rates and taxpayers' associations clamoring for a reduction in tax costs. I am quite in agreement that something must be done to relieve the burden on real estate, but I find that so-called efficiency experts and heads of taxpayers' associations make one of their first strikes in economy moves in matters relating to fire protection, suggesting the closing of fire stations and discontinuance of fire companies, organizing efforts to oppose replacing fire apparatus that is old and in dangerous condition and also refusing to get behind a proposition to provide hydrant service for areas that are remote from such protection.

I want to repeat again to this gathering that I feel that both the water superintendents and chiefs of fire departments should take stock of their stewardship and find out if there is some way in which they can still further reduce costs of operation without impairing efficiency. I think the heads of these departments should take the initiative of showing and publicizing the fact that they have made economies, and, further, I think these heads should be on the alert to combat any movement to curtail on the necessary services that their departments are giving to the municipality. Those who are interested in reducing taxes should understand that services for the protection of the lives and property of a municipality should be the last to suffer curtailment. A municipality could lose many lives due to faulty apparatus breaking down on the way to a fire, and some of the largest and most valuable pieces of property could be consumed in a fire and probably never replaced, thus eliminating from the tax list of the city a very large income.

Therefore, I want to leave with you the thought that I am not advocating curtailment of any functions necessary in any department but I do urge you to scrutinize costs, determine where leaks are, plug them up, and show taxpayers that the money being spent in your department is absolutely necessary and essential for their safety and welfare.

MAINTENANCE OF WATER WORKS EQUIPMENT

BY SHERMAN L. ROGERS*

[*Read April 27, 1939*]

"Now, in the building of chaises, I'll tell you what,
There is always somewhere a weakest spot,—
In hub, tire, felloe, in spring or thill,
In panel, or crossbar, or floor or sill,
Find it somewhere you must and will
And that's the reason beyond a doubt,
That a chaise breaks down but doesn't wear out."

Oliver Wendell Holmes wrote these lines many years before most of our modern machinery was even thought of. The moral of the poem is still more or less true, but I think that a statement that machinery "breaks down but doesn't wear out" would be slightly inaccurate.

In waterworks operation, it is most important that machinery and equipment be in the best possible condition for instant use, especially emergency equipment that may be required at any moment to control or repair breaks in large pipe lines. To control a break similar to one which occurred in a 30-in. cast-iron main in West Hartford last winter, we have a 1½-ton truck equipped with maps, gate locations, gate wrenches and other tools. A gate-closing mechanism for closing down the larger valves with the truck motor is also installed on this truck. With this mechanism a 30-in. gate which would ordinarily take four men 30 minutes to close by hand can be closed in 10 minutes.

This particular break, in which one length of 30-in. pipe split from end to end, occurred at about 10 a.m., and service was completely restored within 9½ hours. To accomplish speedy repair work like this, we keep a trailer tool box at our main yard, completely equipped with boots and enough hand tools to get repair work well under way. This eliminates delay while tools are being assembled from various jobs.

Since a large proportion of our main streets have a concrete base, an air compressor is usually needed to break down the pavement. We have five compressors and a Barco gasoline-driven paving breaker. Two of the compressors are truck-mounted portable units and three are powered from the motors of the trucks on which they are mounted. Each compressor carries two paving breakers, two clay diggers, two

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tampers, a sump pump, and those on main-pipe work also carry air-caulking and chipping hammers.

The latest addition to our fleet of compressors is shown in Fig. 1.

FIG. 1—MOBILE AIR COMPRESSOR, HARTFORD, CONN.

This is a 13-in. wheelbase Ford with the cab over the engine which also furnishes power for the compressor unit. The inside of the body is equipped with seats for the men and bins to carry various fittings used on service-pipe work.

Before a system of periodic tests and checkups was inaugurated, it was a frequent occurrence to have an air tool break down when most needed, or else to have the foreman complain that the compressor assigned to him was no good because it would not run two paving breakers. Each operator now brings his compressor to the shop for a four-hour inspection and checkup every fifth week. The air output is first measured on the air meter to determine efficiency. Air consumption tests are then made on the air tools while the mechanics check over both compressor and truck engines. On power takeoff units, the speed of the compressor is also checked, since this depends on the setting of the governor and needs occasional adjustment for proper operation. Oil is changed, plugs, distributor and carburetor cleaned, and the whole outfit tightened and inspected.

The air meter is shown (Fig. 2) with a paving breaker connected for a test in the lead pot. The hose of the compressor is connected to the meter through the connection at the left in the illustration. A

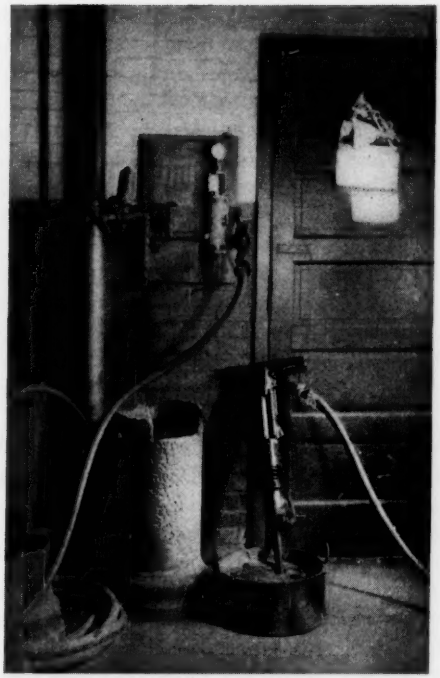

FIG. 2—AIR METER FOR TESTING COMPRESSOR EFFICIENCY AND AIR CONSUMPTION OF PNEUMATIC TOOLS, HARTFORD, CONN.

flat-pointed moil point is placed in the breaker and worked in the lead for ten seconds. The air consumption in cubic feet of free air per minute is meanwhile being noted from the meter. A 2-in. penetration into the lead is required with an air consumption not exceeding 68 c.f.m The breakers that we use were originally rated to take about 55 c.f.m. of air when new, but this gradually increases with wear. When making our first tests, we found several hammers that took 80 c.f.m. or more of air, or 75% of the total output of the compressor. A breaker such as this appears to do as much work as ever, but if two such breakers were connected to a 105-cu.ft. compressor something would appear to be wrong right away, and formerly it was the compressor that took the blame.

Excessive air consumption can sometimes be reduced by taking the air tool apart and cleaning it, but if it has been used without oil and the cylinder is scored, or if it is badly worn, it is necessary either

to install oversize pistons or have the cylinders built up by the chrome process. This process is very satisfactory, and the cost is approximately half that of a new paving breaker. Oil is very important in the operation of paving breakers, and we insist that the oil reservoirs in the handles be filled at least twice a day. During cold weather, three gallons of oil are diluted with one gallon of kerosene and one gallon of alcohol. The alcohol prevents the tools from freezing and the kerosene serves to dilute the oil and also helps it to mix with the alcohol.

The clay diggers and tampers are given an air consumption test while the sump pumps are tested in a tub of water. Air consumption alone is a fairly accurate indication of the amount of water a pump will lift. We find that the pumps require about 80 c.f.m. of air to handle 180 g.p.m. while the clay diggers require about 33, and the tampers, 28 c.f.m.

Automobiles and trucks are also inspected at monthly intervals. This has proven to be a very good investment. Since inspections were started, there has not only been a decided improvement in the general condition of the units, but breakdowns on the road have been much less frequent.

All cars are washed and greased bi-weekly by the night emergency men, and after every other washing are kept in the shop the next day to allow a mechanic to go over the unit, tighten the chassis, adjust brakes, carburetors and other equipment. Defects that cannot be repaired in the four hours allotted to the mechanic to work on the car are reported to the foreman, who makes arrangements for the work to be done at a later date. In this way the yard foreman has a definite knowledge of the condition of the cars, and there is no excuse for breakdowns.

The cars are all equipped with oil filters, and oil is changed only twice a year. The filter cartridges are changed whenever they become dirty, which varies between 4,000 and 6,000 miles, depending on the condition of the motor. At one time we had about fifteen drums of crankcase drainings. To use up this old oil a Skinner Oil Filter was set up in our filter plant, where our own electricity is available. This filter takes the impurities out of the spent oil and its output is about 2 g.p.d. The effluent with an SAE number of about 30 has been used successfully in the older trucks for nearly two years.

The average cost per mile for operating 23 half-ton pickup trucks was 3.65¢ last year, and for operating eight 4-ton trucks, 6.3¢. These

costs include office overheads, insurance and tires, but do not include depreciation.

All pumps, large tapping machines and similar equipment are checked after being used. By this procedure, all equipment is kept in condition to operate at all times.

Much the same procedure is followed in the care of meters. We plan to bring into the shop each year one fifth of all our meters. This program, which was started in 1932, was completed for the first time in 1936 when we tested over 9,000 meters.

Although we now have 2,160 more meters than in 1934, last year 467 fewer meters than in 1934 were removed for all causes other than regular tests. We believe that this improvement is largely due to eliminating the weak links before they break down.

Upon arrival at the shop, all meters are tested at a rate of ¼ their rated capacity, after which each meter is torn down, washed, and reassembled with any necessary new parts. Every repaired meter is then tested and must meet the requirements of the NEWWA specifications for accuracy of new meters.

All worn gear trains are repaired in the shop and certain of the chambers are remachined and pistons refitted to the chambers. Other chambers are repaired at the various meter factories, if we cannot quickly fit new discs to them ourselves. When repaired meters were first required to meet the NEWWA accuracy requirements for new meters, it was necessary to revise our testing procedure. Previously, on the minimum test flow, which in the case of a ⅝-in. meter is 0.25 g.p.m., we ran water at this rate through the meter for three minutes. For a 100% registration, the meters should read 0.1 cu. ft. Since it was almost impossible to differentiate between 0.08 and 0.09 cu. ft. and since 0.09 was required for the meter to pass, it was necessary to run a full foot of water into a one-foot test tank. This takes 30 minutes, and it seemed a waste of time and labor to have a man spend a half hour watching water run into a can.

The present electrical apparatus (Fig. 3) was rigged up to meet this condition. The flow is now started by opening a solenoid valve. When the test tank is filled, a float in the tank closes an electrical circuit which trips the valve and shuts off the water. The volume in the tank is controlled by this means to within 0.1%. By this means it is possible for one man to test two strings of 8 meters each simultaneously, and on each flow enough water is run so that the test hand of the meter always makes at least one complete revolution.

In Fig. 3, the water goes through the meters which are at the

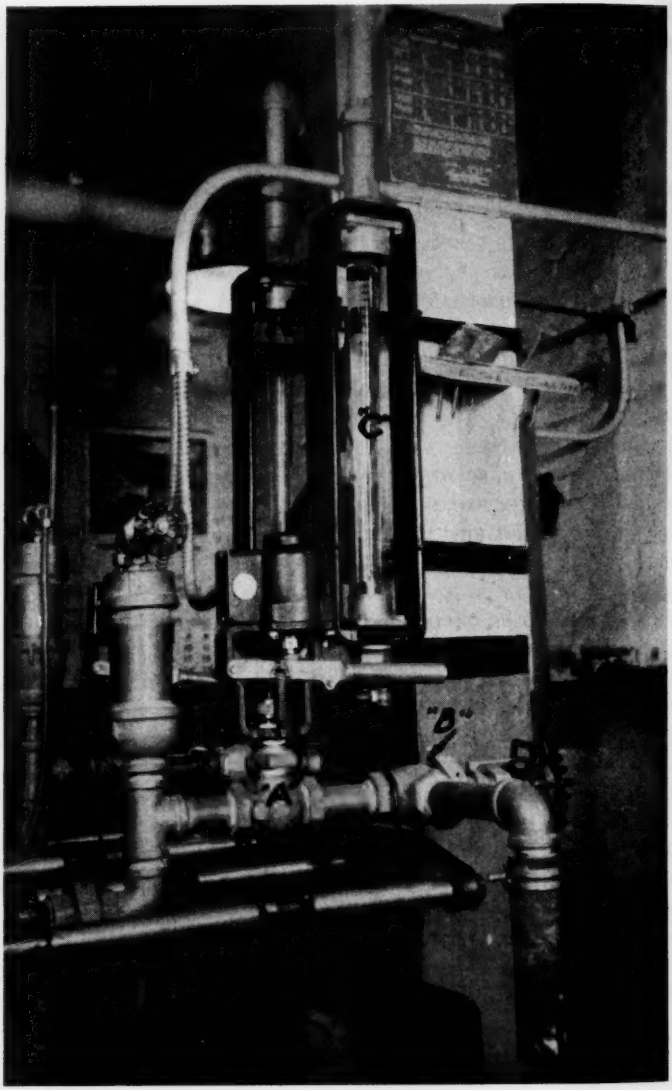

FIG. 3—ELECTRICALLY CONTROLLED METER-TESTING EQUIPMENT, HARTFORD, CONN.

left of the picture, thence through the solenoid valve "A" and the flow-control valve "B" to the Ford test-rate indicator "C", and then to one of the two tanks shown in Fig. 4. The large one is of 10-cu. ft.

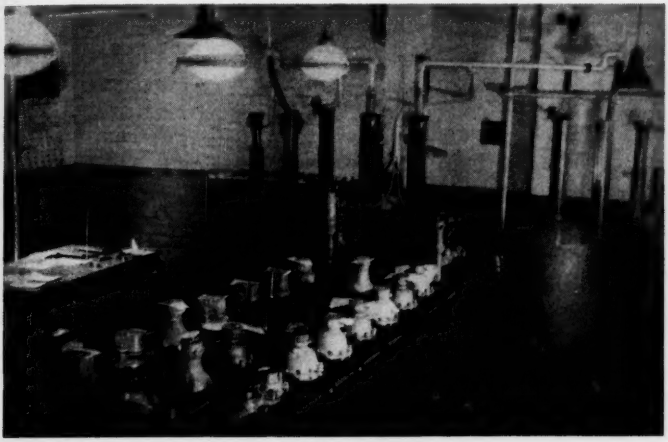

FIG. 4—METER-TESTING EQUIPMENT, HARTFORD, CONN.

capacity and the smaller one holds 1 cu. ft. Each has a conical bottom and a reduced section at the top for greater accuracy. One of the two pipes coming out of the top of the tanks is used for filling, and the other contains the float.

This work is under the direction of Caleb Mills Saville, Manager and Chief Engineer of the Water Bureau of the Hartford (Conn.) Metropolitan District, and of Harold W. Griswold, Deputy Manager and Deputy Chief Engineer.

IMPROVEMENTS IN POWER AND PUMPING FACILITIES OF THE MANCHESTER WATER WORKS

BY PERCY A. SHAW*

[*Read May 25, 1939*]

Manchester is supplied by a dual water system. The Low-pressure system was built in the early 70's when the population of the city was only 22,000. In 1894, the town having spread out to higher land, the High-pressure system was started.

The Low-pressure Pumping Station is located at the outlet of Lake Massabesic where a 40-ft. head is available from the crest of the impounding dam to the tailrace. All water was originally pumped by water power.

The High-pressure Station was built on the west shore of the West Pond of Massabesic Lake at a point three miles from the Low-pressure Station. The writer has never been able to find sufficient reason for locating the High-pressure Pumps away from the Low-pressure Station. The High-pressure Station was originally operated entirely by steam.

Later a transmission line was built from the Low-pressure Station and electrically-driven centrifugal pumps were added at the High. The transmission line between the two stations was made a 33,000-volt line with the idea of connecting it later directly to the high tension supply lines of the Public Service Company. Purchased power is now taken from a 4,000-volt distribution line of the Public Service Company. We still plan to tie in with the high-tension system by building about three miles of 33,000-volt line. This connection will save two transformations for the High-pressure Station, eliminate a 4,000-volt transformer inside the Low-pressure Station and improve the certainty of power supply. Electric power generated at the Low-pressure Station at 2,300 volts is used there at 2,300 volts by the pump motors and also stepped up to 33,000 volts for delivery at the High-pressure Station where it is stepped down to 2,300 volts for power use. Between the pumping stations and the distribution system on both systems there are large distribution reservoirs storing a week's supply of water and permitting pumping at convenient hours. The High-pressure System can feed the Low, but there is now no provision for pumping from Low to High.

*Superintendent and Engineer, Manchester Water Works, Manchester, N. H.

In 1935, the hydraulic turbine in use at the Low-pressure Station was an old twin, horizontal shaft, Trump Turbine working under a net head of about 40 ft. The machine was not of modern design, running parts were rather badly worn and the hydraulics of the setting were not good. We rebuilt the turbine casing and the connection to the penstock, reset the big 60-in. valve in the penstock line and replaced the entire rotating unit of the machine with a pair of S. Morgan Smith high-efficiency turbine wheels installed in the rebuilt casing.

Careful tests of the old turbine indicated that the over-all efficiency of the turbine and its direct connected 375-k.v.a. generator was 72% and of the turbine itself about 76%. The new turbine was guaranteed to have an efficiency of above 88% over a wide range.

We equipped the penstock gate, which is located just above the turbine, with a pair of little water turbine motors to open and close it; so that, when not operating, no water would leak through the turbine gates. The new turbine gates can be set and kept so that they will leak less than 1% of the normal full gate demand of the turbine; but when closed down for long periods, the penstock gate itself should be closed. We estimate that the old turbine gates leaked about 10 c.f.s. continuously when the turbine was not in operation. As it required four men at least two hours to close the old gate, it was seldom closed, even for summer shut-downs. One thing that operators of all kinds of plants should remember is that things that are difficult to do often do not get done. Nearly all of the water formerly wasted through the old turbine is saved by the tight gates on the new turbine and by the use of the penstock gate during long shut-downs. Saving 10 c.f.s. at all times when the unit is not in operation is an important power saving. With this water, our new machinery at the Low-pressure Station would pump 233 m.g. in a year of average runoff. We estimate that the over-all increase in efficiency of power realized from water by these changes in the turbine and setting amounts to about 21%. The saving in water wasted by leakage will add an additional 23% to the power formerly obtained.

At this Low-pressure Station there were two pumps. These were horizontal shaft, centrifugal pumps, direct connected to induction motors. One pump, rated at 8 m.g.d. would pump 6.6 m.g.d. and the other, rated at 6 m.g.d., pumped 5.4 m.g.d. This lower capacity was due to friction in settings and force main. Our studies led us to believe that by well designed piping the friction loss in the station

could be cut to less than one half and that the power saving would pay for the cost of relocation and repiping of the pumps in less than three years. Fortunately there was ample room in the station for a properly laid out system of piping. Tests conducted in 1935 showed that friction losses in the setting, that is in suction and discharge piping, for the 8-m.g.d. pump amounted to 15.7 ft. and for the 6-m.g.d. pump to 19.8 ft. With the new setting and new and rebuilt pumps pumping 8.3 m.g.d. and 7.5 m.g.d. respectively, suction and discharge losses are 6.3 ft. and 9 ft. respectively.

The larger pump, which with its 250-hp. motor was pumping 6.6 m.g.d., was moved over and given reasonably good piping conditions, although some old material was used with the idea that later this pump would be replaced by a new one. The entire rotating element was replaced with new shaft, impeller, etc., and to our surprise the rebuilt pump using the old casing showed an efficiency of 86% and pumps 7.5 m.g.d. Its efficiency before rebuilding was 71.3%.

The old 6-m.g.d. pump was discarded and replaced by a new 8-m.g.d. pump with a guaranteed efficiency of 89%. The discharge from this line was made of 20-in. pipe instead of 12-in. and 14-in. In the DeLaval testing plant, this pump showed an actual efficiency of 90.0%.

At the High-pressure Station we have a 6 m.g.d. vertical, triple-expansion Snow steam pumping engine. The steam for this engine is produced by a pair of old Manning boilers. This pumping engine has been used for pumping when water power was not available, because with our present electrically-driven, centrifugal pumps, steam power is somewhat cheaper than purchased power. However, our boiler plant is old, having been installed in 1910, and if it is to be used for steady pumping much longer the entire steam equipment will have to be replaced. It is hardly likely that the required capacity can be put in our present boiler house. Replacing of the steam boiler plant, therefore, means not only new boilers but new housing. It has been our idea that we could so improve our water power and our centrifugal-pump efficiencies that the steam, or other stand-by, would be required only a small proportion of the time; and also that with more efficient centrifugal pumps we could afford to purchase electricity at our present rate (1.5 cents per k.w.h. without a demand charge) rather than pay for changes in the steam plant, boilers, cost of coal and labor for operating. We therefore plan ultimately to eliminate the steam. A gasoline- or Diesel-operated pump would be installed for strictly emergency use.

At this station there are also two centrifugal pumps direct-connected to electric motors. One rated at 5 m.g.d., driven by a 400-hp. motor and purchased in 1917, was found to handle 5.6 m.g.d. The other pump, rated at 3 m.g.d., with a 200-hp. motor, purchased in 1915, was found to have its rated capacity. These pumps should handle more than their rated quantity of water due to the fact that a 24-in. force main from this station to the reservoir was added to the original 20-in. main, greatly reducing the friction head against which the pumps worked.

The piping of these pumps is obviously bad from a hydraulic point of view. This is a result of jamming two pumps into available space without regard to hydraulic losses in the suction and discharge piping. For the 5-m.g.d. pump the friction loss was 18 ft., while in the three miles to the reservoir the loss through the 20- and 24-in. pumping mains totals only 6½ ft. The setting for the 3-m.g.d. pump is even worse so far as high velocities and sharp bends are concerned, but the quantities of water pumped are less and this pump is used only as a stand-by. The steam pumping engine is piped with much more regard for friction loss.

The friction losses in the station were measured with a mercury column. With its present setting, the 5-m.g.d. pump shows a friction loss of 10 ft. from the pump well to the pump and 8 ft. from the pump to the force main. With large piping, easy bends and proper reducers and increasers, we estimate that we can pump 7 m.g.d. with a total suction and discharge loss of 4.7 ft. as against the present 18 ft. while pumping 5.6 m.g.d. With a 7-m.g.d. pump, the loss in the force main will increase from 6.3 ft. to about 15 ft. We estimate that changes in piping will be paid for by power saved in about three years.

At the Low-pressure Station each percent of efficiency of the pumps, based on hours actually operated and purchased power, is worth $120 per year; and each foot of friction head costs $50. At the High-pressure Station these figures are $124 and $33 respectively.

The present 5-m.g.d. pump has an efficiency of 70.0% and the 3-m.g.d. pump 66.0%. We are working against a higher head here than at the other station but expect to get a guaranteed efficiency of at least 85% for a new 7.0-m.g.d. pump.

There has probably been no great reduction in the efficiencies of these pumps since they were installed. Improvement in the art of centrifugal-pump design, at least for the large sizes of pumps, has been very considerable in the last 15 years. This improvement has

been partly in the design of the impeller and partly in the design of casing and has followed the improvement in water turbine design. Twenty years ago, pumps of the size we are discussing had a maximum efficiency of about 70%, while now efficiencies between 88 and 90% are guaranteed and delivered. This is an increase in efficiency of over 25%. Small pumps for small quantities of water are still produced with very low efficiencies compared with large pumps. I believe that the small-diameter deep-well pumps are an exception, due to there having been sufficient demand for efficient pumps to cause development of even very small pumps having an efficiency as high as 80%. The huge new pumps for the Los Angeles water supply from the Boulder Dam project have an efficiency well over 90% due to special tests on small scale units. The motors and pumps for these stations look like vertical turbine and generator settings.

We have started work at the High-service Station by replacing the rotating unit in the 5-m.g.d. pump. After removal of the steam turbine, we plan next to reset this pump with proper suction and discharge piping. We expect that in its new setting it will deliver about 6.5 m.g.d. with the same motor. We shall then replace the old 3-m.g.d. pump with one of about 7-m.g.d. capacity.

Extensive and somewhat elaborate calculations of the probable increase in pumping by water power, when all the proposed changes have been made, indicate that whereas we averaged to pump about one half of the water at both stations with water power previous to 1938, we should now pump, in years of normal rain fall, all the water at the Low-pressure Station and 60% of that at the High-pressure Station. Taking into consideration improvements in water wheel efficiency, losses of water stopped, and improvement in pump efficiencies and settings, the over-all improvement is about 60% at the Low-pressure Station and will be about the same at the High.

These results are due partly to improvements in the use of water in making power and partly to increase in efficiency of pumps and pump settings. We wish particularly at this time to emphasize the increase due to pump settings, as we find that, even in some of the new modern stations, space has been saved at the expense of proper piping. If calculations of friction losses had been made, better piping would have shown a very large percentage return on the increased investment.

Tower Hill Reservoir which has a capacity, for water works purposes, of 1,300 m.g. has, for water power purposes, a capacity of 160 million cubic feet, or 70 second-foot months; or it will store

enough water, if only filled once each year, to pump all the water now required by the city of Manchester for about a month. This reservoir is being built in coöperation with W. P. A. The water works cost for this project will be justified by the benefit to our water power alone. The fundamental purpose of the reservoir, however, is improvement in the water supply.

These described improvements in power and pumping facilities have been made under the general supervision of the writer. Tests, engineering studies and construction were started under our former Assistant Superintendent, Mr. John Hollis Read, and since his untimely death have been the direct charge of Mr. Clarence L. Ahlgren, Mechanical Engineer for the Department.

COMPARISON BETWEEN THE 1916 AND THE 1938 SPECIFICATIONS FOR GATE VALVES

BY SAMUEL E. KILLAM*

[*Read May 25, 1939*]

The committee of the American Water Works Association to revise the standard specifications for valves as adopted in 1913 and revised in 1916 was appointed on December 7, 1929.

The first draft was presented by this committee on April 8, 1931, and after a series of conferences and various revisions to the original draft, tentative specifications were approved in 1937 which were reedited and approved by the Water Works Practice Committee on April 25 and adopted by the American Water Works Association's Board of Directors on April 29, 1938. They were then transmitted to the New England Water Works Association with a request for approval and were referred to a special committee who reported back to the Executive Committee with the opinion that these specifications, while not ideal, were probably as good as could be obtained at the present time, due to economic and other conditions.

The Executive Committee of the New England Water Works Association approved the specifications on February 16, 1939, and these specifications were effective as a basis of purchase on May 1, 1939.

During this long period, the committee of the American Water Works Association, under the able leadership of G. Gale Dixon as Chairman, had labored faithfully to get these specifications into concrete form. Many obstacles had to be overcome in connection with this work, and it should be borne in mind that most of this work had to be done through correspondence with various officials throughout the country and then ironed out with the committee from the manufacturers.

May I take the liberty to illustrate this by quoting from some of the correspondence.

From a well-known operator in the West:

"We do not use the old specifications and probably would not use the new specifications. Our experience of the past twenty years with

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the old commercial valve has been entirely satisfactory and we would not feel warranted in going for a better quality."

From a well-known consulting engineer in the East:

"The question of cost will be important and if the new valves involve much additional cost the consumer will continue to demand the lower price valves, the makers will continue to furnish them and the standardization will be defeated."

From a well-known operating superintendent in Massachusetts:

"If your committee will produce a gate valve that will satisfy and insist that the manufacturers produce the same, your committee will have done something for the water districts of the country that will be of lasting benefit."

From the manufacturers' committee referring to suggestions made to be included in the specifications:

"Their inclusion would tend to restrict competition and to increase sales expense."

Thus from seventy-four pages of closely-typed report, covering suggestions made by operating superintendents, consulting engineers, and manufacturers throughout the country from which it was necessary to eliminate many proposed features in order to overcome objections of both the operators and manufacturers, this material was boiled down to twelve pages. So far as possible the new specifications are tied in with the specifications of the American Society for Testing Materials for material used in the construction of all valves.

The set-up of the new specifications is very helpful as there is a table of contents in which are listed the various items covered by the specifications. This makes it much easier to find the definite requirements for each item. Under Section 1 is given definite information as to just what the specifications embrace. This section also provides for special requirements of installation and operation, calling the attention of the operator to the fact that such conditions are beyond the intended scope of these specifications and will require special consideration in matters of design and construction. Section 2 calls attention to the fact that it will be necessary to make supplementary specific statements as to definite requirements in regard to details.

The new specifications make the following requirements not mentioned in the old specifications:

Thicknesses and disposition of metal in bells shall be such as to produce strength not less than that of bells of Class D, A.W.W.A. standards.

Flanged and gate valves shall conform in dimensions and drilling to American 125-lb. cast-iron flange standard.

Gate rings shall have a minimum compressive strength of 4,000 lbs. per sq. in.

Flanges, where oversize, shall be spot-faced.

Body rings shall be back-faced; the threads accurately cut and the rings screwed into machined seats in the body.

Body and bonnet shell thicknesses taken at points diametrically opposite shall, when added together and divided by two, equal or exceed the minimum metal thicknesses given in the drawings. Shell thicknesses at no point shall be more than 12½% below the minimum metal thickness called for in the drawings and no continuous area of deficient thickness shall exceed 12½% of the superficial area of the casting.

Types of gates, rings, wedging devices, guides, tracks, stuffing boxes, cast-iron gears, steel gears, indicators, by-passes, thrust bearings and gaskets described; and area of guides for gate bearings specified.

Casting marks shall include working water pressure and special marks, if required.

The following are other important points in the new specifications which differ from the old specifications:

The new specifications require a minimum body thickness specifying A.S.T.M. specifications A126-30 to be used for all iron castings and also that the tensile strength of iron for valve bodies and bonnets 10 in. and larger be not less than 30,000 lb. per sq. in. and for less than 10 in. in size 21,000 lb. per sq. in. The old specifications did not specify the minimum body thickness and the tensile strength for the iron for all sizes was 22,000 lb. per sq. in.

The new specifications require a minimum tensile strength up to 80,000 lb. per sq. in. for valve stems depending on the size; whereas the old specifications allowed only 45,000 lb. per sq. in. for all sizes of stems.

Bronze alloys shall have an elongation of 15% in 2 in., while the old specifications permitted 5% elongation in 8 diameters.

The socket dimensions shall conform to A.W.W.A. Class C standards up to and including 24 in. Sizes 30 in. and larger shall be as specified. The old specifications required the valves to have hub ends suitable for laying with Classes B and C of the A.W.W.A.

Bolts and nuts shall be rust-proof and of steel conforming to A.S.T.M. specifications A107-36. They shall also be semi-finished

when bearing is on finished surfaces. The old specifications required that the bolts and nuts be made from double refined iron or steel.

The valves shall be tested by opening and closing and by applying a hydrostatic pressure at 300 lb. per sq. in. and 100 lb. per sq. in. Under the 100-lb. test, all joints and seats shall be perfectly watertight. Under the old specifications, tests on wedges called for 300 lb. per sq. in.

The stem minimum diameters are the same as the old standards, except for the 3-in. valve, the diameter of which is increased. The minimum threads per inch are specified.

The old specifications specified weight of finished valves for the various sizes. This has been eliminated in the new specifications as the same and better results will be accomplished by specifying the thickness of the metal.

All work under these specifications shall be subject to inspection and approval by the purchaser's duly authorized engineer or inspector, who shall at all times have access to all places of manufacture where materials are being produced or fabricated or tests are being conducted and shall be accorded full facilities for inspection and the observations of tests. Any gate valve or part that he may condemn as not conforming to the requirements of these specifications shall be made satisfactory or shall be rejected and replaced.

The manufacturer is also required to use due and customary care in preparing valves for shipment so as to avoid damage in handling or in transit. Valves 24 in. in diameter or larger shall be securely bolted or fastened to skids in such a manner that they may be safely unloaded with a crane.

In this short paper, I have endeavored to point out the essential differences between the 1916 and the 1938 valve specifications. May I add that while it may seem from some operator's point of view that the latest specifications are not entirely satisfactory, there is a clause that permits any consumer who desires a better-built valve to make changes and additions in these specifications, provided that he is willing to pay for the additional costs.

SOME POPULAR MISCONCEPTIONS CONCERNING THE FUNCTION, VALUE AND SIGNIFICANCE OF WATER ANALYSES*

BY CHARLES D. HOWARD†

[*Read May 25, 1939*]

Since the inception of the Laboratory of Hygiene, more than 65,000 water analyses have been made. At the present time the number of such is several thousand annually, these being divided between (1) municipal water supplies, which are under periodic analysis and inspection, (2) supplies of semi-public character, and (3) sample submissions representing residential well and spring sources. During the past biennium, 3,000 samples of the last-named origin were examined, the great majority of these involving a "complete sanitary analysis,"—by which is meant both chemical and bacteriological examinations based upon gallon sample submissions.

Analysis and Interpretation of Data Afforded. To form the basis of the report, two phases, or steps, are involved, viz.: (1) the analysis proper, which is a comparatively simple matter of technical routine performed by a qualified assistant, and (2) interpretation of the significance of the data, which not infrequently is far from a simple matter, calling for expert knowledge and experience, involving, as it essentially does, a form of "diagnosis," or expression of judgment, based upon a consideration not only of all the data afforded by the analysis, but upon as complete information as is obtainable concerning the identity, location and character of the source and of associated conditions. The latter constitutes what is known as the inspectional (environmental) evidence,—a factor that is always of importance as suggestive of the presence or absence of potential hazards and as affording an assisting and pertinent means of judging concerning the ultimate safety in conjunction with the question of the immediate potability of a supply.

Purpose of Requested Information and Significance of Data. To the end of obtaining this information as fully as possible, certain questions appear on the card to be returned with the sample by the sender. Not infrequently these questions fail to be answered, there sometimes being in evidence a disposition to suppose that such in-

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formation might serve to influence the analyst or prejudice the character of the report rendered. Such a view is altogether erroneous and unwarranted, being based upon a misconception of what is involved and of the nature and essential limitations of water analysis. So far as the analyst is concerned, he merely records what he actually finds, such findings being in no wise biased by any statements borne on the sample card.

For the most part, the data afforded by a sanitary analysis do not involve items which of themselves are necessarily deleterious to health. To a large degree these analytical items are merely quantitative "indicators," relative in character, which, when so utilized, serve as evidence of the present degree of purity and, with limitations, of what is or may have been transpiring in association with the source. Hence, necessarily the significance to be attached to some of these items will vary somewhat, especially as concerns whether the supply is one of ground or surface origin.

Thus degrees of color, organic matter and numbers of bacteria that would be recognizable as not abnormal in a surface source would be quite out of place in a well or spring and could be accepted as denoting an inadequately protected source or an otherwise improper condition.

Excessive chloride (salt) is apt to spell sink drain seepage, yet it may be and not infrequently is due to a history of salt refuse deposited near a well, or to "thawing out" a frozen pump, or to calcium chloride used for dust-laying on a nearby highway, drive or tennis court, or to proximity to the sea—in the latter connection reference being involved to a so-called "normal chloride map," which shows the normal chloride content of waters of known purity for every town in the State. As, unlike in some other localities, there are no saline deposits in New Hampshire and chloride is *not* contained in any of our soils, regardless of depth, in more than minute traces, the minute quantities which our waters normally do carry are to be attributed to marine influence. Hence, increased chloride, though harmless of itself, has a diagnostic significance, and an explanation is to be sought in the sanitary surroundings.[1]

Similarly, excessive nitrate (also harmless of itself), usually attributable to seepage from privy, cesspool, barnyard or nearby manured soil, may arise from an application of chemical fertilizer (nitrate of soda) to nearby lawn or garden, or to shrubs or plants close to the well. Substantial *nitrite*, denoting as it ordinarily does

[1]The application of a softening treatment may serve to increase chloride substantially.

a state of "instability," and something quite out of place in a pure well or spring water, may actually be due, with excessive ammonia, to reduction of nitrate through galvanic action of such water in galvanized pipes, in such case being without sanitary significance. Here, the results of a test for zinc are revealing. Appreciable "free ammonia" is abnormal to spring water, indicating as it does a decomposition of albuminous matter; yet it sometimes normally occurs in the water of deep wells, and it also tends to be normally present in rain water, resulting here from the action of electrical discharges upon the nitrogen of the atmosphere.

Water from "Hard-pan". Both substantial hardness and iron may be and not uncommonly are normal to a source. Yet any sudden development of these items, where previously not in evidence, is a circumstance very suspicious of an associated development of pollution. The water of wells newly sunken in "hard pan" soil quite frequently exhibits not only a more or less pronounced and disagreeable odor but also some excess of vegetable matter. In such case neither of these items signifies lack of safety. Both, as well as a frequent association of iron, arise from normal soil constituents, the odor probably being due to decomposition of sulphur compounds therein. Nevertheless, such water is scarcely potable, although fortunately the condition usually clears up in time, as the well is pumped.

Water Analysis Not Comparable to an Assay. Hence, while interpretation of the significance of some of the items of a sanitary water analysis where in substantial quantity may properly require judgment in the light of associated information, and such an analysis tends in general to be in a different category from that of many substances, this is by no means to imply that interpretation of the results necessarily is always a matter calling for critically expert judgment. Thus as to data concerning metallic impurities, hardness, alkalinity and general physical character, the findings are such as to admit of no debate and they can be evaluated by any tyro in water analysis.

Incidentally, many quantitative determinations are made for lead. As this is a time-consuming operation and would be effort wasted unless the water traversed lead pipe, it is done only when the sender so indicates. An old story, long-persisting and popularly accepted as reflecting upon this department, involved the case of a sender who thought to be smart and who submitted two samples actually drawn from the same section of lead pipe, one so designated on the sample card, the other not. The fact that no lead was reported for the second was by him accepted as proof positive of the unreliability of the analysis!

It also is obvious that where the analytical data throughout are compatible with those recognized for clean water, it can readily be declared that that water was "pure" *at the time of sample collection.* That is, in no wise is such a report to be accepted as a guaranty of continued purity or that conditions attending the source are such that a hazard of contamination at some future time is necessarily non-existent.

Knowledge Concerning Environment Important. Here is where the value, the very important function of inspection enters. Not only is the latter true of ground water sources (where time and again evidences of unsafe conditions have thus been revealed), but it is pre-eminently so as to sources of surface origin. Thus it is obvious that if a well lacks adequate protection, or a privy overhangs a stream, or barnyards skirt its banks, or there is extensive bathing, boating or fishing in a pond, or the watershed tends to be actively frequented by men or animals—then there is a hazard of contamination. This remains true regardless of what the examination of a single sample may show. To repeat, *such sample merely denotes the condition of the water existent at the moment of sampling;* it cannot guarantee what that condition was yesterday or may be tomorrow, or for that matter, what it may be in the next hour, or at some other point on the supply. This principle is of vital importance in any consideration of the safety of a surface supply.

Analysis of Surface Sources. As concerning surface sources, the importance of the inspectional function and the fallacy which may attach to a few individual negative laboratory tests alone has been demonstrated repeatedly in the past in connection with this department's efforts to secure improvements in and the imposition of modern recognized safeguards on our public water supplies. Too often the local officials have been "doubting Thomases." They have pointed to the fact of a non-typhoid history—as though this were the one and only ailment likely to be contracted from contaminated water; also, there is failure to appreciate the fact that the modern science of sanitation is based upon prevention through the removal of existing hazards.

As a "clincher," a popular local step has been to "send a sample to Boston,"—which city being a recognized fount of wisdom, any finding emanating therefrom, virtually regardless of by whom or what the degree of experience, must be accepted as absolutely and finally conclusive. There is paid a fee of perhaps ten or twenty-five dollars—which of itself must mean advice more valuable than that which from

the State costs nothing! And in due course a report is received which, we are triumphantly told, indicated the water to be "one hundred per cent pure." That should settle the question! Of course, any really competent private investigator would sharply qualify his finding, with due explanations in his report. But, while this may have been done, no intimation of it ever has been transmitted to this department in such instances.

The Analysis for Bacteria. Another seemingly non-debatable finding which may result from a sanitary water analysis is that of the presence of *B. coli,* by which in common parlance is meant those bacterial organisms constituting what bacteriologists designate as the colon-aerogenes group. A generation ago there was comparatively little application of the science of bacteriology to water analysis, the latter then being dependent upon the application of chemical, physical and microscopical methods. But during the past century the bacteriologist has tended very largely to usurp the position of the chemist in this field. While bacteriological methods are unquestionably tremendously important in this respect, a tendency in evidence for some years is the assumption that the bacteriological examination is the only one of any real consequence and that the long established practice of making a chemical analysis in conjunction is now become one that might as well be discarded.

We are likely to find such an opinion in evidence on the part of physicians, as well of others who have had no especial experience in water analysis and whose knowledge of the application of advanced sanitary chemistry necessarily is limited. "Germs" are something more appealing to the understanding, more spectacular, immediately concerned as they are with the transmission of disease. Repeatedly we receive well or spring samples from persons who advise that they are interested only in a bacteriological analysis. It is desired to learn whether or not any "typhoid" may be present,—the typhoid organism commonly being confused with the colon organism, which latter, although similarly of intestinal origin, is a very different "animal" and *of itself* harmless as occurring in water.

Such requests on the part of water sample senders not infrequently tend to fall in much the same catergory, though in reverse, as those on the part of milk sample senders who tell us they are "not interested in the bacteria" but wish to learn if the milk is of good quality. Such persons, of course, fail to comprehend what they really need to learn.

Negative Bacterial Findings Not Proof of Safety. There is no

disposition here to dispute that as concerns surface water sources—ponds and streams—the bacteriological part of the analysis is paramount. It is indispensable to the determination of sanitary fitness and safety—always, however, having due regard here for the twin facts, (1) that the sanitary inspection of the watershed is of equal or even greater importance, (2) that while a positive finding is a definite danger signal, a *negative* bacteriological finding given by a single sample affords no guaranty of safety. One investigation is essentially a complement of the other.

Two Varieties of Colon Organisms. Two members of the so-called colon-aerogenes group are recognized, namely, fecal and non-fecal types. True *B. coli* are the organisms characteristic of the excremental matter of all warm-blooded animals—luxuriantly present normally in the intestinal tracts of both man and beast. The precise origin of the very closely similar other type, also contained in fecal matter but in smaller number, is still a moot question. Not improbably it is a result of metamorphic change, through which it has adapted itself to a hardier environment. This type is more resistant and tends to a wider distribution. Because of the general similarity of behavior on standard laboratory media, it is not customary to attempt to differentiate it from the first-named in the routine analysis of water—nor is there any very pronounced need of such differentiation, inasmuch as both are to be deemed out of place in drinking water of suitably clean and satisfactory quality.

Non-Differentiation Between Coli of Human and Animal Origin. Furthermore, a point which requires special emphasis here is that up to the present time it has not been found feasible by any standard procedure to distinguish coli of human origin from those contained in the excretions of animals. Hence, a "positive" finding in water is by no means to be accepted as evidence of contamination of human origin; it can well be due to farm animals or, for that matter, to wild species.

Here, again, is where the value of inspection arises. At most, a positive colon finding—*always properly quantitated*—serves as an indictator of contamination, a red flag of danger. To repeat, the colon bacillus and the typhoid bacillus are not the same thing. The point is that where coli are found in water, typhoid or other pathogenic organisms *may* be there also. In other words, a colon-contaminated water is to be accepted as unsafe.

Yet even so, the unwary can well be misled at times concerning the true significance, or the extent of significance, of such a laboratory

finding. One reason why this is so is because where inspectional knowledge justifies a presumption that the coli are of animal origin, the degree of danger is much less than would be the case were human wastes involved, the hazard of contraction by man of disease from animals being more remote. Another reason is that where sample collections are made by a layman, the coli found in the sample may not necessarily represent coli actually in the water but instead be due to infection of the sample in the process of collection—as from dirty hands, dirty and leaky faucets, or unclean methods, containers or other facilities utilized for drawing from a well or spring. Repeatedly, it has been demonstrated that sample infections have thus occurred, the water itself having been innocent.

Value of Complete Sanitary Analyses of Wells and Springs. Where ground water sources are under periodic inspection and analysis, the routine bacteriological examination alone, when supplemented by an occasional chemical one, may suffice. Otherwise, it is important that both forms of examination be made. This is for the reason that the chemical analysis may indicate an unsafe condition—indeed, a water quite unfit to drink—and yet the result of the bacteriological examination of the sample at time of collection be negative. Thus, it quite frequently happens that a series of chemical analyses of a well water may uniformly denote drainage, from such an item as privy, sink drain, cesspool or barnyard, with an accompanying bacteriological analysis that is only occasionally positive.

This serves in a measure as refutation of the argument of the bacteriologists as to the lack of value of chemical water analysis. For, while there is ground for the contention that the soil is an effective filter and hence that we can ignore to some extent those chemical findings which the analyst refers to as evidence of "past pollution," yet too great dependence should not be imposed upon any theory that natural soil filtration will be continuously and under all conditions effective. As a matter of fact, the experienced water analyst knows full well that such is not the case.

But assuming that it were, who is there amongst discriminating persons content to quaff filtered dishwater or clarified cesspool or septic tank effluent? The fact that one may for years drink such water without experiencing health impairment,—or, perhaps more properly, without suspicion of it as being a cause of ill health—is beside the point. Some persons, indeed, actually acquire in the course of time a liking for a certain flavor inherent in such water, as compared to a "flat" flavor, or want of flavor, which they note in a pure

water. It is analogous to the "nutty" taste which some miss when manure finally is eliminated from the milk supply, also to the milder, more delicate flavor of maple syrup manufactured by modern sanitary methods as compared to that of the crudely made product of years ago.

Bacterial Contamination of "Pure" Water. On the other hand, it is a fact that not infrequently a water sample may be, as judged by the criterion of chemical analysis, of an acceptable degree of physical and organic purity and yet the presence of *B. coli* may be in evidence. Such cases usually involve temporary contamination and usually are ascribable to inadequate construction or protection of the well or spring—an exceedingly common fault. Where the covering is not water-tight, as it should be, traces of infective matter readily can be introduced from shoes, or from such a circumstance, for example, as poultry running over the platform, such contamination in at least bacterially-infecting quantity being carried in through splash from the pump or by rains. Some well owners are duly meticulous about providing a tight covering of cement, except for leaving an opening to provide "ventilation,"—a wholly unnecessary expedient. Others choose to cling to the attractive but insanitary old open well and bucket, while still others are guilty of removing water from uncovered springs by dipping.

Wells as a Cause of Typhoid. In the days before public water systems were generally provided, when cesspools in cities and towns abounded, and there was commonly resort to public wells within compact areas, the latter undoubtedly served as an active and prolific medium for the dissemination of typhoid fever and kindred diseases. Hence, the fear that exists and the reputation in the popular mind that long has been attached to wells as an agency in this connection. While there are, of course, notable exceptions, yet speaking generally, wells today, at least those in the rural sections, do not deserve this reputation, despite the fact that the first thing done in the event of a case of typhoid is to investigate the water and milk supplies,—and properly so.

In this connection it is necessary to appreciate that typhoid does not originate in dirty water; first, it must be implanted there, which means there previously must have been in the neighborhood of such well, a case—whether acute or of the "walking," or carrier type. Hence, inquiry as to any such circumstance is to be sought out immediately. As a matter of fact, flies and an open privy vault are more likely than the farm well to be the responsible agents of transmission. So far as probabilities as to the well are concerned,

we have, first, the bacteriologist's own argument that "soil acts as a filter," second, the fact that a few typhoid bacteria emplanted will not survive for a very long period in the average well, although it is true that clean water affords these organisms a more favorable environment than does a dirty one.

And because this is so, because the infecting organisms may be present today and not tomorrow and because a case of typhoid does not become in evidence for some two weeks following the date of infection, it can well be that a bacteriological examination of any water made at the onset of the disease may afford a negative result, even though such water actually was the responsible medium of dissemination.

Hence the possible fallacy in placing emphasis upon the results of a bacteriological water analysis where a typhoid case is encountered. Such analysis is quite the proper and logical thing to have. By all means it should not be omitted. But back of all is the imperative need of search for the actual causative agent, meaning a prior case of typhoid, or a food-handling "carrier."

Concerning Report of Analytical Data. In the case of samples periodically submitted from public water systems, the superintendents of which have acquired some acquaintance with the analytical data and who need to receive this for its comparative value, the reports rendered are inclusive of such data. But because to the average layman such data is about as intelligible as would be so much Chinese, this, unless specially requested, is omitted from reports so made, the latter embodying instead a statement of the findings in simple language, with any pertinent recommendations, and with references to informational and explanatory matter printed on the form.

In rare instances the recipient of such a report may feel he is not thus receiving "his money's worth" in connection with this free service. There was the case of the man who responded with a particularly pugnacious and abusive letter in which he implied a belief that no actual analysis had been made, that we had passed judgment upon merely the appearance of the water. Demanding we reimburse him for the express charges "within three days, or I will go higher," he announced his intention of sending a sample to another laboratory "for a real analysis"!

What Certain Authorities Say. Roseneau, in his authoritative and well known work, "Preventive Medicine and Hygiene," thus aptly sums up some of the points here discussed:

"There has been much conflict and useless discussion between

chemists and bacteriologists concerning the relative advantages of their methods. The chemists were first in the field, but the limitations of chemical methods were strongly emphasized when it was shown that chemistry can only indicate pollution but cannot discover infection. Much was hoped from bacteriology, but it is exceptional that bacteriologists are able to isolate *pathogenic* micro-organisms from a sample of water. For the most part, the routine bacteriological examination of water does nothing more than the chemical examination, that is, it shows contamination but does not prove infection. Both chemical and bacteriological analyses of water have, therefore, distinct limitations; they do not antagonize, but supplement each other."

The following in conclusion is relevant. The somewhat iconoclastic sanitary authority, Chapin, once said that the principal danger attaching to a cesspool is the possibility of someone falling into it. This is a bit extreme. The dictum of another authority, Sedgwick, that he would rather have one hundred dead humans buried in the watershed of a water supply than one live one walking about on top of it, is more credible. For it is true that but little danger is likely to attach to the use of water of wells located in the neighborhood of cemeteries, despite a popular belief to the contrary.

GROUND WATER IN THE PRE-GLACIAL BURIED VALLEYS OF MASSACHUSETTS

BY IRVING B. CROSBY*

[*Read September 13, 1938*]

The importance of ground water in Massachusetts is recognized and nearly a million people depend upon it for their water supplies,[1] but it may not be so well known that there are still many good opportunities for developing important ground water supplies even in the more populous parts of the state. Relatively little is yet known about the ground water carrying deposits of the state, and it is the purpose of this paper to explain certain principles that will aid in the location and development of new ground water supplies.

There are two lodgements for water underground: in the hard rocks and in the overburden. Although many small ground water supplies come from the hard rocks, most of the ground water supplies in Massachusetts sufficient for municipalities come from the overburden. Ground water in the hard rocks of New England was discussed by the writer in this JOURNAL[2] six years ago, and this paper will be confined to ground water in the overburden.

Practically all the overburden of Massachusetts, indeed of New England, is of glacial origin. It is either material deposited direct from the ice as glacial till, or material that has been transported and sorted by running water as clay, silt, sand, gravel, or glacial material transported by wind and redeposited. The glacial till is a heterogeneous mixture of fine and coarse sediments. Some of it contains everything from clay to boulders and is appropriately called boulder clay. This is commonly known as hardpan. Glacial till is relatively impervious, and although small supplies may be obtained from dug wells, it is an unsuitable source for municipal supplies. For these, the large quantities of water necessary can only be obtained from the coarser sands and gravels. The glacial till is thickest on the hills and ridges and is often in the form of hills with rounded profile and elliptical ground plan, known as drumlins. The clay, silt, sand and gravel were deposited in water and are consequently in the valleys.

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[1]Kingsbury, Francis H., Public Ground Water Supplies in Massachusetts. *This Journal*, 50 (1936), pp. 149-197.

[2]Crosby, Irving B., Relation of Geology to the Ground Water Supplies of New England. *This Journal*, 47 (1933), pp. 74-95.

Importance of Buried Valleys in Location of Ground Water. The valleys of Massachusetts were formed by stream erosion when the sea stood lower in relation to the land. Those valleys were consequently cut below the present sea level and extended out beyond the present shore line. When the sea rose, the outer parts of the valleys were drowned.

At the close of the glacial period, great quantities of débris were washed from the ice and deposited in the valleys, partially filling their headwater parts, completely filling their lower parts, and sometimes blanketting the intervening ridges, with the result that there is now no visible evidence of some of these valleys. The valleys in the central and western parts of Massachusetts are partially filled with glacial deposits, but the divides are seldom buried. In eastern Massachusetts, on the other hand, the valleys are sometimes completely filled with glacial outwash, and the divides are partially buried. The present streams wander on the surface of these glacial deposits, often cross buried divides from one old valley to another, and follow courses entirely different from the pre-glacial drainage. There are, therefore, many buried valleys in the bed rock beneath the present surface of eastern Massachusetts.

These buried valleys are filled with deposits of clay, silt, sand and gravel. There are some deposits of sand and gravel in the form of eskers, or winding ridges, and kames or knolls between these valleys, but such deposits seldom contain important ground water supplies. In some cases, however, eskers buried by impervious material may provide water that moves underground from an adjacent area. Large ground water supplies are generally confined to the larger deposits of sand or gravel in the buried valleys. The location of these buried valleys, therefore, becomes the first step in a search for ground water. If this search were dependent entirely upon drilling, it would be very slow and expensive, but fortunately it is possible to find geological clues that are of great aid in tracing out these buried valleys.

As one casually looks at the surface in the flatter parts of eastern Massachusetts, there is no apparent indication of a system of buried valleys entirely different from the present system of valleys, but if one understands the principles of the development of valleys in this region and is thoroughly conversant with its physiography, clues begin to appear. An extensive study has been made of the buried valleys of eastern Massachusetts using field observations, physiographic principles, existing boring data, and geophysical methods, and the location

of a few of the important buried valleys has been determined. Several very successful wells that had previously been put down were proved to be in large buried valleys where they could draw ground water from a large area.

On Cape Cod and about as far north as Plymouth, bed rock is buried so deeply that even the ridges between the buried valleys are far below sea level. That region is deeply buried beneath a great moraine deposited about the termini of two lobes of the ice sheet. Ground water supplies are found in the coarser parts of these morainal deposits and many have been developed.[3] Since, however, the bedrock surface is far below sea level, the water supplies are not controlled by the buried valleys. Therefore, this paper is restricted to eastern Massachusetts, excluding Cape Cod and adjacent territory. In the central and western parts of the state, the location of the buried valleys is much simpler because the dividing ridges are seldom buried.

Having located the buried valleys, the second step in the search for ground water supplies is to find the deposits of sand and gravel in those valleys. This is sometimes done by wildcat drilling which is very slow and expensive. It is, however, possible to learn much about the location of these deposits by geological investigations. These deposits were laid down in accordance with certain geologic principles and, with an understanding of those principles, it is possible in many cases to forecast conditions beneath the surface.

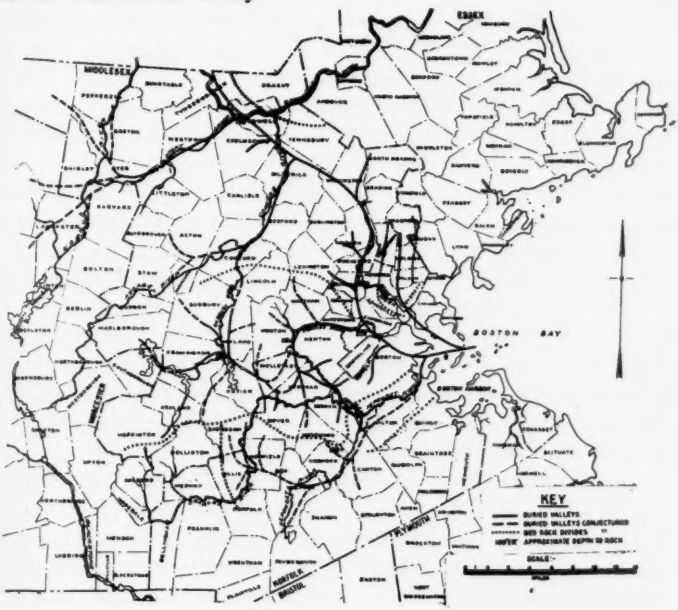
The more important buried valleys will now be described, the deposits in them will be briefly explained and the aid of geology in locating these deposits will be discussed. Some of the ground water supplies found in these buried valleys will then be mentioned.

In discussing ground water in these buried valleys, the writer wishes to emphasize that this water does not flow in underground rivers. True underground rivers do occur in limestone caverns, but there are no such caverns in the rocks of eastern Massachusetts, and it is incorrect to speak of underground rivers here. The ground water occurs in the pores of the glacial deposits and in the cracks and pores of the rocks and moves very slowly through these deposits. It is probable that there is a very slow movement of the water down the buried valleys, but it is so slow and of such wide extent that it is misleading to think of it as forming underground rivers.

The Buried Valleys. Boston occupies a lowland surrounded by higher hills of granitic rocks. The pre-glacial drainage pattern of this region was the typical branching pattern seen in much of the non-

[3]Howard, Paul F., Low Velocity Gravel-packed Wells. *This Journal*, 51 (1937), pp. 424-429.

glaciated parts country. We might reflect, therefore, that this lowland, the Boston Basin, would be the focal point where several streams joined to form a larger stream, and such was the case. A deep buried valley comes down from the north by Mystic Lakes and Fresh Pond to Allston where it was joined by the pre-glacial Charles which followed the same general course, below Riverside as the present Charles, but at a lower level. The valley of the joint stream passes under the South End and Dorchester Bay where it was joined by the pre-glacial Neponset which came from the southwest. The valley coming from the north is in line with the projection of the buried valley of the Merrimack, and these valleys will be described as the pre-glacial Merrimack-Mystic Valley, although it is not yet proved that these were one continuous valley.[4]



THE BURIED VALLEYS OF THE PRE-GLACIAL MERRIMACK-MYSTIC, SUDBURY-CHARLES AND NEPONSET RIVERS.

The Merrimack-Mystic Valley. The Merrimack River now flows over ledge, at an elevation of about 90 ft. at Pawtucket Falls in Lowell, but 2 miles upstream at the Lowell Waterworks, bedrock is

[4]Crosby, W. O., A Study of the Geology of the Charles River Estuary and the Foundation of Boston Harbor. Report of the Committee on the Charles River Dam, 1903, see p. 351.

at sea level or lower.[5] The pre-glacial Merrimack was flowing at least 100 ft. lower than the present river, and obviously it could not have followed the course of the present river on account of the rock ridges at Pawtucket Falls and elsewhere.

The right angle bend in the present river just above Lowell is abnormal, and we should expect the buried valley to continue its southeasterly course. Rock is known to be low southwest and south of Lowell, and continuing southeasterly is a pathway free from ledges through Wilmington to the border of Woburn. A broad valley continues through the hills of Woburn, and wells in North Woburn, East Woburn and Winchester show that there is a deeply buried valley. It has not yet been proved whether the pre-glacial Merrimack Valley continued through the hills and was continuous with the buried valley in Woburn or whether there was a low divide near the Woburn-Wilmington line. If the pre-glacial Merrimack did not go this way, it probably flowed easterly from Wilmington towards Salem. In any case, we know that there is a continuous valley, now filled with glacial deposits, extending down through Woburn, Winchester, Arlington, Cambridge, Allston, and the South End to Dorchester Bay. Even though there may be a low buried bed rock divide near the Woburn-Wilmington line, the effect is much the same as regards ground water, and for convenience, this will be treated as one valley.

The Nashua River now follows an abnormal northeasterly course to the Merrimack River at Nashua. Study of the physiography makes it clear that the pre-glacial stream did not follow this course and that it probably flowed easterly from Ayer through the broad valley now occupied by Stoney Brook, to North Chelmsford where it joined the pre-glacial Merrimack.[6] The pre-glacial Nashua was formed by the junction of several streams in or near Ayer.

A stream flowed down the valley of the Concord River into the pre-glacial Merrimack, but this pre-glacial Concord was smaller than the present Concord River because the Sudbury River was not tributary to it. The pre-glacial Merrimack had other small tributaries in Massachusetts, some of which are indicated on the map.

The pre-glacial Merrimack had its source in New Hampshire and flowed through the valley now occupied by the present river as far as the Lowell waterworks. The old river was, however, at a lower level, and its channel was often at one side or the other of the present channel. In several places, the modern river has cut down upon

[5]Crosby, W. O., Geological History of the Nashua Valley during the Tertiary and Quaternary Periods. *Technology Quarterly*, 12 (1899), see pp. 300-320.
[6]*Technology Quarterly*, 12 (1899), see pp. 303-306.

rock ridges that projected into the pre-glacial valley, and rapids or falls have resulted. This is the explanation of the falls at Hookset and of Goffs Falls and Garvins Falls. Although the Merrimack is now in its old valley, it is helpful to locate its old channel in connection with ground water investigations.

As can be seen on the map, there is thus a burried valley extending from New Hampshire to Boston, and it has an important tributary valley extending from Ayer to North Chelmsford. Billerica, Lowell, Reading, Wilmington, Woburn, and many industries and institutions obtain water from wells in these valleys and their branches, and it is probable that successful wells can be obtained in other places as will be explained later.

The Sudbury-Charles Valley. The modern Charles River occupies parts of the valleys of several pre-glacial streams. The upper part of the Charles Valley formerly drained southerly into Narragansett Bay, the central part was tributary to the Neponset, and the northern part joined the pre-glacial Merrimack-Mystic at Allston as has been described.[7] The buried valley that probably leads from the upper part of the Charles Valley to Narragansett Bay has not been studied, but there may be opportunities along its course for ground water supplies. The water supplies of Medway and Franklin are from wells in this valley. The other two old valley systems will be described insofar as they are known.

There appears to be a buried pre-glacial divide in Dover between the central and northern parts of the Charles Valley as can be seen on the map. The pre-glacial Charles was, therefore, a small stream extending from the hills of Dover to Wellesley and thence to Alston where it joined the pre-glacial Merrimack-Mystic as has been described. The old Charles received a large tributary from the northwest with the result that below Wellesley it was probably a larger stream than at present.

Between the Charles Valley in Wellesley and the Sudbury River in Wayland, the land is low, mostly sand plains, containing several ponds and swamps. The surface features suggest a burried valley, and borings prove its existence. The borings at Morses Pond for the Wellesley water supply did not reach rock at a depth of 85 ft., which is 25 ft. above sea level. Borings for the proposed Metropolitan tunnel show that under part of Lake Cochituate rock is more than 86 ft. below sea level. There is thus indication of a deep buried

[7]Clapp, Frederick G., The Geological History of the Charles River, 14 (1901), pp. 175-201.

valley extending southeasterly from Wayland to Wellesley, and we will call this the pre-glacial Sudbury Valley.

The present course of the Charles River from Wellesley to the ocean is very irregular and abnormal, and it is evident that its pre-glacial course was different. The pre-glacial Sudbury made a great bend in the western part of Wellesley and followed a northeasterly course to Riverside. Its exact course through Wellesley is uncertain, and it may have swung farther to the south and east into the edge of Needham. In either case, it was joined in Wellesley by the small pre-glacial Charles. The present winding course of the Charles from Dover to Newton Lower Falls is entirely post-glacial and occupies parts of valleys of several small pre-glacial streams that were tributary to the pre-glacial Sudbury-Charles. It has been thought by some that the Charles was once tributary to the Neponset in the vicinity of Mother Brook, but this cannot have been the case because the two valleys are separated by a rock ridge and the valley of the old Charles was at a much lower level than the crest of this ridge. From Riverside, the course of the old Sudbury-Charles was similar to that of the present Charles as far as Allston where the old River joined the pre-glacial Merrimack-Mystic and flowed southeasterly by the South End instead of going northeasterly as at present.

The course of this old river is normal and fairly direct, except for the bend to the south through Wellesley, and this is explained by the geology. The old Sudbury followed the shortest course to the softer rocks of the Boston Basin. In Wellesley, it encountered a belt of slate which it followed northeasterly to the pre-glacial Merrimack-Mystic at Allston. To have continued directly east from Wayland would have taken it through the granitic hills of Weston, and to have continued southeasterly from Wellesley into the Neponset valley would have necessitated crossing a ridge of granitic rocks in Dedham. The old river thus chose the path of least resistance.

There remains to be considered the upper part of the pre-glacial Sudbury. This stream appears to have come from the northwest via South Sudbury. Geophysical prospecting has shown a buried valley more than 100 ft. deep at South Sudbury. This and other evidence indicate that the pre-glacial Sudbury came from the vicinity of Hudson, probably draining the upper part of the Assabet Valley, and flowed via South Sudbury, the north end of Lake Cochituate and Morses Pond into Wellesley where it was joined by the small pre-glacial Charles coming from the hills of Dover. A tributary flowed east from the vicinity of the Sudbury Reservoirs joining the main

stream near the northern end of Lake Cochituate. There is evidence of two other tributaries as shown on the map, and there were probably many other tributary brooks that have not yet been located.

The pre-glacial Sudbury-Charles was an important river system in this part of the state, and its buried valleys underlie a considerable area. Wells of the water supplies of Brookline, Dedham, Natick, Needham, Newton, Waltham, Wayland, and Wellesley are in these buried valleys, as are also many private wells. It appears probable that much additional water could be obtained by wells in other places, especially northwest of Wellesley, and it is reasonably certain that the safe yield of these buried valleys has not yet been reached.

Charles-Neponset Valley. The pre-glacial Charles-Neponset River had its sources in Medfield, Sherbourne, and Millis, and flowed easterly into Walpole, thence northeasterly to Boston Harbor. From Walpole to the Harbor, it occupied the valley now traversed by the present Neponset River; its channel, however, was much lower and in a different location from the present channel. The exact location of this channel is uncertain, but in Milton it is believed to pass south of Brush Hill and Milton Hill. An important tributary came from Canton, and it is not yet known how far south the valley of this tributary extended. Near Reservoir Pond, a well shows bed rock far below sea level, and it seems probable that this buried valley extends many miles to the south and that it formerly drained a large area. The water supplies of Canton, Medfield, Millis, Norwood, Sharon, Walpole, and Westwood are obtained from wells in the buried valleys of the pre-glacial Charles-Neponset River and its tributaries. In addition, there are many private and institutional wells in these valleys. It is probable that additional successful wells can be located in these valleys and that further exploration through the southeast will discover buried tributary valleys and ground water supplies in Sharon, Stoughton, and adjacent towns.

Deposits of the Buried Valleys. We have now discussed the locations of those buried valleys in eastern Massachusetts that are known, and we have mentioned briefly the means of obtaining information about them. Unfortunately, these valleys do not contain water-bearing sand at all places, and it is necessary to study the deposits to learn the most likely places for wells. Where the deposits filling the buried valleys were laid down by running waters, they usually consist of sand and gravel; but where the valleys were occupied by glacial lakes, the sediments were deposited in standing water and the deposits are usually fine-grained, consisting of clay, silt, and

fine sand, all unsuitable for wells. There are, however, tongues and deltas of coarser sand extending into these lake deposits.

The glacial deposits of this region have not yet been studied in sufficient detail to make possible the location of water-bearing sands without further study, but there is much general information that aids in such an investigation. The deposits of the different valleys will now be discussed in a general way, and possible locations for additional ground water supplies will be mentioned.

Deposits and Ground Water Supplies of the Nashua-Merrimack-Mystic Valley. The Nashua Valley was occupied by a glacial lake that extended from East Pepperell to the Wachusett Reservoir. Great quantities of fine sediments were deposited in this lake, but there are areas of coarser deposits, and many successful wells have been obtained in this valley and its tributaries. The water supplies of Ayer, Shirley, and West Groton are from wells in these valleys. It is probable that additional successful wells can be located in these valleys, but careful study of the glacial deposits will be necessary.

As has been explained, the course of the pre-glacial Nashua River is believed to have been from Ayer to North Chelmsford. The water supplies of North Chelmsford and Westford are obtained from wells in this valley, and the supply of Littleton is from wells in a tributary to this valley. It is probable that many additional wells can be located in the pre-glacial Nashua drainage system and that much additional water can be taken from these valleys without exceeding the safe yield.

The Boulevard well field of the Lowell water supply is in the Merrimack Valley and the Cook and Hydraulic well fields, formerly used by the city of Lowell, are in the buried valley of the pre-glacial Merrimack south of Lowell.[8] The new wells for Billerica are in a tributary of this, the pre-glacial Concord valley, as are the Bedford wells, and the Chelmsford wells are in a small branch valley. The wells for the water supplies for Wilmington, Reading, and Woburn[9] are in the pre-glacial Merrimack Valley or in tributary valleys. Many industries and institutions obtain water from wells in these valleys. It is possible that additional wells could be located in Billerica, North Reading, Reading, Tewksbury, and Wilmington, but careful study of the deposits will be necessary. Much additional water can probably be taken from the pre-glacial Merrimack Valley without exceeding its safe yield.

[8]Bowers, George, Result of Tube Well Experiments in Lowell. *This Journal*, 13 (1899), pp. 30-35.
[9]Wentworth, John P., Additional Ground Water Supply for Woburn, Mass. *This Journal*, 50 (1937), pp. 430-436.

Deposits and Ground Water Supplies of the Sudbury-Charles Valley. Part of the valley of the pre-glacial Sudbury-Charles River above Wellesley was occupied by glacial Lake Sudbury at the close of the glacial period. Much fine sediment was deposited in this lake, but numerous deltas of sand were built into it, and other sand deposits were laid down in it. The water supply of Wayland is obtained from wells in the bed of this glacial lake, and it is probable that many other successful wells would be located in other parts of this lake basin. A glacial lake, connected with Lake Sudbury, occupied the Charles River Valley above Riverside. Parts of this lake were filled with fine sediment as was proved by test borings near Riverside, but in other parts are deposits of sand and gravel in which are the wells of the water supplies of Brookline, Dedham, Needham,[10] Newton,[11] and Waltham. The new Wellesley well at Morses Pond and the Natick well are in the connecting channel between these two lakes. Framingham and Ashland obtain part of their supply from wells and galleries in a branch valley. Little is known about conditions in the upper part of the pre-glacial Sudbury Valley in Hudson, Stowe and adjacent towns, but it is probable that there are deposits of water-bearing sand and that successful wells could be located there. In general, that part of the pre-glacial Sudbury Valley northwest of Wellesley appears to offer opportunities for large additional water supplies without exceeding the safe yield.

Deposits and Ground Water Supplies of the Charles-Neponset Valley. The pre-glacial Charles-Neponset Valley was occupied by glacial lakes, but there are many deposits of sand in which successful wells have been located. In the upper part of the valley is the supply of the Medfield State Hospital and the supply of Millis. In the central part of the valley are the supplies of Canton, Foxboro, Norwood, Sharon, Walpole, and Westwood obtained from sand deposits in glacial Lake Neponset. Two state institutions at Norfolk obtain water from wells in the southwest part of this valley.[12] Other institutions and many industries also obtain water from these deposits. It is probable that much more ground water is available in the buried valley of the Charles-Neponset River and that additional satisfactory wells can be located, even though parts of these valleys are filled with fine-grained lake deposits.

The Use of Geophysical Prospecting. The use of geophysical

[10]Snow, Bayard F., The Needham Gravel Packed Well. *This Journal,* **51** (1937), pp. 409-423

[11]Sampson, George A., Engineering Problems Connected with the Recent Improvements to the Newton, Mass., Water Supplying Works. *This Journal,* **48** (1934), pp. 88-101.

[12]Snow, Bayard F., The Water Supply of a State Institution. *This Journal,* **50** (1936), pp. 197-206.

prospecting has been mentioned and will now be briefly described. Geophysical prospecting may be used to obtain various kinds of subsurface information without drilling. Two methods are of use in engineering investigations: the electrical method and the seismic method. The electrical method was first used in foundation studies by the writer in 1928 at Fifteen Mile Falls on the Connecticut River in northern New Hampshire.[13] The seismic method has been applied to engineering investigations more recently, but gives promise of being more accurate.

The seismic method can be used to obtain the depth to bed rock. It depends upon measuring the travel time of explosion vibrations in the rock and in the overburden. A small charge of dynamite is buried about four feet deep and exploded, and the arrival times of the vibrations are automatically recorded by a series of seismographs that are placed at equal intervals in line From the records, it is possible to compute the depth to rock at each seismograph and to determine the slope of the rock. A profile of the bed rock surface is thus obtained, and if there is any buried gorge crossing the line of profile, it will show. It is also possible to obtain some information about the character of the overburden. The apparatus is compact and light and is easily used in rugged terrain.

This method has proved very useful in this study of buried valleys. It is far quicker and much less expensive than drilling and is especially suitable for any investigations in which it is useful to learn the approximate depth to bed rock. The method was checked at borings of the Metropolitan Commission and was found to be surprisingly accurate. A depth of 117 ft. was recorded where the borings showed 115 ft.

Résumé of Ground Water Conditions in Eastern Massachusetts. We have seen that the ground water supplies of eastern Massachusetts are found in sand deposits in buried valleys, and we have discussed the ground water supplies in three of the pre-glacial river systems, the Nashua-Merrimack-Mystic system, the Sudbury-Charles system and the Charles-Neponset system, and we have seen that additional supplies can probably be obtained from each of these valleys. Similar conditions probably exist in adjacent parts of Massachusetts, but sufficient investigations have not yet been made to permit outlining them. In Essex County there are probably numerous buried valleys, and as has been stated, it is possible that the pre-glacial Merrimack

[13]Crosby, Irving B., and Leonardon, E. G., Electrical Prospecting Applied to Foundation Problems. Am. Insti. Min. and Met. Engineers, *Technical Publication* No. 131, 12 pp., 1928.

crossed the southern part of this county to the vicinity of Salem. There are many ground water supplies in Essex County, and it is probable that others can be obtained.

Buried valleys also exist in southeastern Massachusetts, and conditions are probably suitable for ground water supplies in these valleys in eastern Norfolk County, northern Plymouth County, and Bristol County. There are numerous ground water supplies in these areas, and it is possible that other important supplies can be obtained. As has been explained, in southern Plymouth County and Cape Cod, the overburden is very thick, bed rock is deeply buried and the ground water conditions are not controlled by the buried valleys.

Conditions in Other Parts of New England. In central and western Massachusetts and in much of the remainder of New England, except eastern and southern Maine, and southeastern New Hampshire, the streams are usually in their pre-glacial valleys, but not in their pre-glacial channels, and the valleys are partly filled with glacial deposits. In these areas, there is no difficulty in locating the buried valleys, but the problem of finding water-bearing deposits in the valleys is the same as has been described for eastern Massachusetts. Numerous ground water supplies are obtained in the sand and gravel deposits of these valleys and much additional ground water can probably be taken from them.

In southern and eastern Maine and in southeastern New Hampshire, conditions are similar to those in eastern Massachusetts. The pre-glacial valleys are usually deeply buried, and sometimes the divides are concealed under glacial deposits. The present rivers often occupy part of several pre-glacial valleys.

The writer has shown in a previous paper that the Androscoggin River formerly flowed south from Bethel, Maine, by Sebago Lake into the ocean south of Portland, Maine.[14] That part of the Androscoggin River below Bethel now occupies the valleys of several pre-glacial streams Such conditions are common in southern and eastern Maine, and it is probable that many valuable water supplies can be obtained from these buried valleys.

[14]Crosby Irving B., Former Courses of the Androscoggin River, *Jour. of Geology*, **30** (1922), pp. 232-247.

BOOK REVIEW

MANUAL OF WATER WORKS ACCOUNTING. Prepared by the Municipal Finance Officers Association and the American Water Works Association. Published jointly by the Municipal Finance Officers Association, Chicago, and the American Water Works Association, New York, 1938. 9x6 in. 483 pp. $4.00.

The Manual of Water Works Accounting, prepared and published jointly by the Municipal Finance Officers Association and the American Water Works Association, treats with water works accounting and administration based on the practical experience of prominent water utility officials. It presents methods more directly applicable to the management of utilities, whether privately or municipally owned, having annual operating revenues of more than $100,000 but less than $250,000, however with minor changes it should prove helpful to those falling within any range.

The manual is generously illustrated with charts and tables adopted from forms in actual use by up-to-date utilities, and with figures which show the various entries necessary to carry out the suggested methods of accounting procedure. As the title states, the book is a manual, with no claim that the methods outlined are the only ones possible of use, but that they should be accepted as based on sound and workable principles, brought together under one cover, for the valuable assistance of those managing a water utility plant

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